Work team building and planning problem : Models and experiments in the service-to-business context

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PROBLÈME DE CONSTITUTION ET DE PLANIFICATION D'ÉQUIPES DE TRAVAIL: MODÈLES ET EXPÉRIMENTATIONS DANS LE CONTEXTE DE SERVICES AUX ENTREPRISES

Devant le jury composé de :

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Abstract

Subcontracting companies organize their agents into work teams and create their work plans to fulfill clients' demands. Multiple constraints have to be met, and several economic and social performance criteria have to be attained. Making a decision, satisfying all these conditions, becomes increasingly difficult, especially in a context of variable demand. A generic problem characterization in the form of a class diagram, containing all the characteristics of the clients, the demands, the agents, the travel routes, and the vehicles, allows us to identify a large number of variants of the problem in the service-to-business as well as service-to-individual contexts. Each variant corresponds to a combination of decision-making problems, demand variability, agents' flexibility, and economic and social performance indicators. We study more deeply two variants, inspired by a real problem found in a Brazilian company in the service-to-business sector, with stable and variable demands. Through a literature review, we identify several potential organizational levers to increase the flexibility of agents, and appropriate modeling and resolution approaches. We use the multi-objective mixed integer linear programming method for the two variants. In the context of stable demand, we consider a compromise between the company's travel costs and agents' work trip duration in a two-level approach: cyclic weekly planning for new customers ensuring assignment stability for a long term and, at a given frequency, re-planning for all active clients, allowing global optimization. When the demand is variable, we consider the reconciliation between the travel costs, the workload balance between agents, and their preference satisfaction for work periods. As planning is made for each short horizon and without repetitiveness, the dependence of agents' activities between consecutive horizons can be relaxed by adding buffer zones between them; in this variant, organizational levers, such as flexible work contracts and multi-skilled agents, are considered.

Keywords: team building, workforce planning, mixed integer linear programming, multi-criteria decision support, variability of demand, flexibility of resources.

Résumé en français

Les sociétés de services aux entreprises constituent des équipes de travail avec leurs agents et organisent leur planning pour satisfaire les demandes clients. De multiples contraintes doivent être respectées, et plusieurs critères de performance économique et sociale doivent être atteints. Une méthode d'aide à la décision multicritère devient ainsi indispensable, particulièrement dans un contexte de demande variable. Une caractérisation du problème générique sous forme de diagramme de classes, contenant toutes les caractéristiques des clients, demandes, agents, itinéraires, et véhicules, nous permet d'identifier des variantes du problème dans le contexte de service aux entreprises comme dans celui de service à la personne. Nous avons investigué deux variantes s'inspirant d'un problème réel d'une entreprise brésilienne de service aux entreprises, dans des contextes de demandes stable et variable. Par une revue de la littérature, nous identifions des leviers organisationnels potentiels pour accroître la flexibilité des agents, et des approches de modélisation et de résolution appropriées. Nous utilisons la programmation linéaire à variables mixtes. Dans le contexte de demande stable, nous cherchons le compromis entre coûts et temps de trajet domicile-travail des agents dans une approche à deux niveaux : une planification hebdomadaire cyclique pour les nouveaux clients assurant la stabilité d'affectation sur un long terme et, à une fréquence donnée, une re-planification pour tous les clients actifs permettant une optimisation globale. Lorsque les demandes sont variables, nous optimisons les coûts de déplacement, l'équité de la charge de travail entre agents, et leur préférence pour les périodes de travail. La planification étant créée pour un horizon court sans répétitivité, l'ajout de zones tampons entre des horizons consécutifs permet de relâcher leur dépendance ; dans cette variante, des leviers organisationnels, tels que des contrats de travail flexibles et la polyvalence des agents, sont également considérés.

Mots clés : constitution d'équipes, planification de personnel, programmation linéaire à variables mixtes, aide à la décision multicritère, variabilité des demandes, flexibilité des ressources.

“Ever tried. Ever failed. No matter.
Try Again. Fail again. Fail better.”

Samuel Beckett

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Minh-Phuoc DOAN (Miller)

Table of Contents

List of Tables

List of Figures

Chapter I. Introduction

Résumé en français

Le problème de constitution et de planification d'équipes de travail se rencontre souvent dans les sociétés de sous-traitance qui fournissent des services pour les entreprises (nettoyage, maintenance et surveillance) ou pour les particuliers (travaux ménagers, soutien scolaire et soins à domicile). Ces sociétés doivent organiser leurs agents dans des équipes pour effectuer des tâches requises sur site des clients. L'objectif visé est de constituer les équipes les plus appropriées et de les planifier en fonction des tâches à réaliser en tenant compte des compétences, des contrats de travail, des contraintes liées à la capacité des agents, afin de minimiser les coûts et de maximiser la satisfaction des clients et des agents.

Notre sujet est inspiré par un vrai problème d'une société brésilienne qui fournit des services aux entreprises et par un autre problème d'une société française qui fournit des services de soins à domicile aux particuliers. J'ai passé un mois au Brésil avec une des entreprises pour le caractériser avec les responsables de la société à différents niveaux. Les demandes de chaque client sont actuellement les mêmes de semaine en semaine, et l'entreprise crée manuellement les plannings de travail pour ses agents et ses clients. Cependant, avec l'évolution des demandes, leur variabilité, les contraintes réglementaires et l'antagonisme entre les différents objectifs à atteindre pour l'entreprise, le problème devient de plus en plus complexe. Le marché des services aux entreprises au Brésil est généralement très concurrentiel. Pour survivre sur ce marché, les entreprises doivent minimiser leurs coûts et maximiser la satisfaction de leurs clients comme de leurs agents. Elles emploient des agents qualifiés et expérimentés pour satisfaire les demandes des clients. Réduire les coûts de déplacements entre le domicile des agents et leur lieu de travail, qui sont à la charge de l'entreprise, est un moyen de réduire considérablement les coûts de service. Ces coûts sont énormes parce que le nombre d'agents et la zone de couverture des services sont très grands. Par ailleurs, le nombre d'agents quittant une entreprise et travaillant pour une autre entreprise dans ce domaine est aussi important. Ils veulent généralement trouver un autre emploi plus près de chez eux pour réduire leurs temps de trajets. C'est pourquoi l'entreprise doit aussi réduire la durée des déplacements pour augmenter la satisfaction de ses agents.

Le problème rencontré en France concerne les sociétés fournissant des services de soins à domicile aux personnes âgées, malades ou en situation de handicap[1]. Les services de soins à domicile en France peuvent être divisés en 3 catégories qui incluent l'aide à la vie quotidienne[2], l'aide à la vie sociale[3] et les actes essentiels de la vie[4]. Le service dans chacune de ces catégories nécessite des soignants avec des niveaux de compétences différents. L'aide à la vie quotidienne peut être effectuée par des soignants peu qualifiés qui ne disposent pas de certification particulière. L'aide à la vie sociale requiert des soignants avec un niveau de compétences plus élevé qui peut être obtenu à travers des formations dispensées par certaines institutions publiques certifiées. Enfin, les actes essentiels de la vie nécessitent des soignants hautement qualifiés qui doivent avoir un diplôme d'État et un minimum de 6 mois d'expérience. Les demandes dans le domaine des soins à domicile sont généralement très variables et dépendent de l'état de santé et des besoins d'activités sociales du client chaque semaine.

Après la crise économique de 2008, nous avons constaté un taux de chômage élevé dans le monde. Les gouvernements de plusieurs pays ont, donc, introduit de nouvelles réformes du droit du travail dans l'espoir de lutter contre le chômage. Les réformes du travail en France[5] et au Brésil[6] en 2017 permettent aux entreprises d'utiliser des contrats de travail avec un nombre d'heures de travail par jour et un nombre de jours de travail par semaine plus flexibles.

Etant donné des demandes clients régulières ou variables et des ressources humaines disponibles au sein de l'entreprise, plusieurs questions de recherche sont à considérer :

- Comment identifier et modéliser toutes les caractéristiques des demandes et des ressources, leurs dépendances, ainsi que les décisions d'affectation des ressources aux demandes en respectant de multiples contraintes ?
- Comment concilier des critères de performance économiques et sociétaux dans la planification ?

[1] https://www.service-public.fr/particuliers/vosdroits/F246
[2] http://www.una.fr/3849-S/agent-a-domicile.html
[3] http://www.una.fr/3850-S/employe-a-domicile.html
[4] http://www.una.fr/3851-S/auxiliaire-de-vie-sociale-avs.html
[5] https://droit-finances.commentcamarche.com/faq/61943-reforme-du-code-du-travail-reforme-macron
[6] https://www.tmf-group.com/en/news-insights/articles/2018/november/brazils-labor-reform

- Comment concilier la stabilité d'affectation dans le cas d'une demande régulière avec une optimisation globale ?
- Comment augmenter la flexibilité des ressources pour répondre aux demandes variables ?
- Dans le cas de demandes et de ressources variables d'un horizon de planification à l'autre, comment gérer la dépendance entre les horizons ?

Pour répondre à ces questions, dans le Chapitre 2, nous proposons un diagramme de classes générique permettant d'identifier toutes les caractéristiques des demandes, des ressources, et des problèmes de décision. Chaque instanciation donne lieu à une variante du problème correspondant à une combinaison de prise de décision, de niveaux de variabilité des demandes, de niveaux de flexibilité des ressources, et d'indicateurs de performance économique ou sociétale. Le Chapitre 3 complète la caractérisation du problème généralisé du Chapitre 2 par une analyse quantitative de la revue de littérature. Une analyse approfondie nous permet d'identifier notamment des leviers organisationnels potentiels pour accroître la flexibilité des ressources. Les Chapitres 4 et 5 examinent deux variantes du problème, inspirées par le problème d'une entreprise brésilienne dans le domaine du service aux entreprises, dans deux contextes différents. Le Chapitre 4 considère le problème dans le contexte de demande stable qui correspond à la situation actuelle de l'entreprise. Plusieurs contrats de travail des agents correspondant à des capacités journalières et hebdomadaires différentes sont considérés. Nous proposons une approche de planification multicritère à deux niveaux: une planification hebdomadaire reconduite pour chaque ensemble des nouveaux clients et, à une fréquence moindre, une re-planification pour tous les clients actifs. Cette approche de planification nous permet d'assurer d'un côté un compromis entre la performance économique de l'entreprise et la satisfaction des agents, et de l'autre côté une stabilité d'affectation tout en prenant en compte les nouvelles demandes des clients. Le chapitre 5 considère le problème dans un contexte de demande variable qui correspond à un « futur attendu » de l'entreprise. Nous spécifions des leviers organisationnels, incluant les contrats de travail flexibles, la polyvalence des agents, et les heures de travail supplémentaires, et évaluons leurs impacts sur la résolution du problème. Par ailleurs, nous proposons une approche de modélisation de la dépendance entre les horizons de planification « dépendant avec des zones tampons », intermédiaire entre indépendant et dépendant pur ; la première est une approche classique mais n'est pas très réaliste, la deuxième correspond à une approche industrielle réaliste mais trop contrainte. Finalement, le Chapitre 6 donne des conclusions et perspectives pour de futures recherches.

1.1. Problem origin

The work team building and planning problem is often found in subcontracting companies that provide maintenance, cleaning, or surveillance services to businesses such as banks, hospitals, and shopping centers. This problem also appears in the service-to-individual domain, when considering activities such as tutoring, housework, or home health care. The subcontracting companies have to organize their employees (also called agents) into work teams to perform required tasks at clients' workplaces. When building teams and assigning them to specific tasks, companies want to attain different objectives, including minimizing their costs and maximizing the satisfaction of their clients and agents while still respect different constraints, such as agents' work capacity, on-time task delivery requirements, and agent-task compatibility.

In the service-to-business domain, our problem is inspired by a real problem of a subcontracting Brazilian company. This company has signed a strategic partnership agreement with the Brazilian co-supervisor of our PhD project that allows us to exploit their private database. As part of the joint agreement, I spent one month in Brazil to work with the company. This stay helped me better understand their problem through discussions with company managers at different levels: the CEO, and the managers of the human resources, client relations, and activity planning departments.

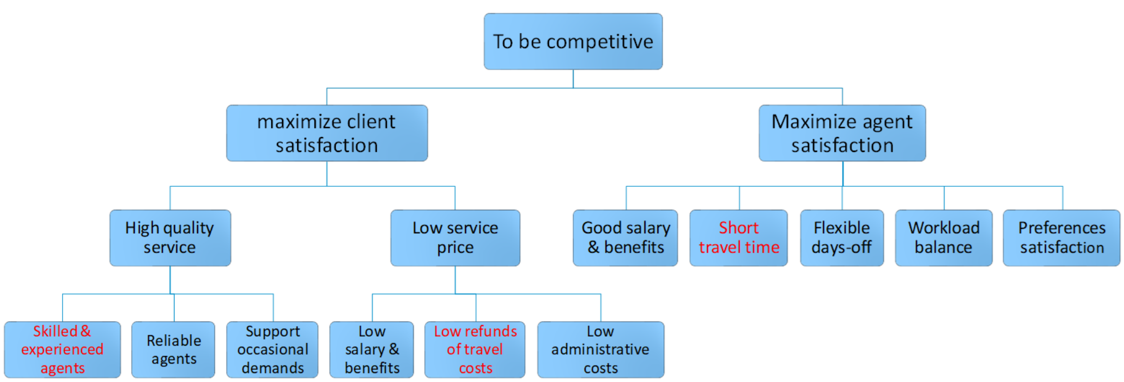

Figure 1. Company's main focuses (in red color) to increase its competitiveness

The company is providing cleaning, concierge, and surveillance services to businesses in more than 200 municipalities of four Brazilian states. The service-to-business market is generally quite competitive in Brazil. To survive in this market, companies always try to maximize the satisfaction of their clients and agents. Through some formal meetings with the top managers, we understand the challenges that they are facing and the solutions they are focusing on (Figure 1).

To maximize clients' satisfaction, they are focusing on hiring skilled and experienced agents to fulfill clients' contracts and reducing service costs, especially the travel costs between agents' homes and their workplaces. Choosing agents with enough skills and experience for tasks is important to ensure service quality. For example, the skills required for hospital cleaning are more complex than those for factory cleaning; an agent who is used to working at a factory, therefore, cannot be assigned to a task in a hospital without additional training. Moreover, several agents working together for a task must be managed by a leader. Several groups working together must have a supervisor. These factors have to be taken into account when choosing agents for a client contract.

Reducing travel costs is a significant way for the company to reduce the service price. The agent's salary is generally identical between companies in the same service domain and the same region and therefore, appears not to be an interesting type of cost to be considered. The travel cost, on the contrary, is a very interesting topic. In this service-to-business domain, client demands are usually located in city centers while most of the agents live in the suburbs. The company has to refund their agents for each work trip they take (usually by public transport). These costs are huge because the number of agents and the service coverage area are generally big. Besides, the number of agents leaving a company to work for its competitors is significant. They usually want to find another job being closer to their homes to reduce the time spent on traveling to work. That is why apart from minimizing agents' travel costs, the company also wants to increase agents' satisfaction by reducing the work trip duration between their homes and workplaces.

The company's managers are creating work plans for agents and clients manually. "We recruit constantly. For example, last time, we interviewed 30 candidates and accepted three of them. These were put into the waiting list for jobs. Then, we chose which agent to assign to which task, depending on their profiles and the distance between their homes and the clients' sites. We recruit new employees and assign them to all the clients' contracts arriving in the same period". This means that different decomposition techniques are currently used to simplify the manual planning process. These include the territorial, work contract, and demand type decompositions. The territorial decomposition technique is used to divide the large service coverage regions into small zones (districts, cities, or municipalities) and solve the problem inside each zone separately. The work contract and demand type decompositions limit the number of demand types that an agent with a certain work contract can fulfill. This technique significantly reduces the number of feasible solutions for manual planning and appears to be useful in the context of stable demand when each agent-client assignment is fixed for a long time. However, with the growing numbers of demands and potential agents, as well as regulatory constraints, even with these decomposition techniques, the problem still becomes more and more complex, which requires more sophisticated solution methods.

In the service-to-individual domain, our problem is inspired by the real problem of French subcontracting companies that provide home health care services to elderly, ill, or disabled people[7]. The home health care services in France can be divided into 3 categories: daily living assistance, social life assistance, and essential acts of life. The daily living assistance concerns basic daily services like meal preparation, daily short interview, and laundry. The social life assistance includes the services that help clients with their social life activities such as shopping, running, and doctor visiting. The essential acts of life involve the services that help the clients, especially highly vulnerable people, with their essential life activities such as toilet, dressing, and moving assistance. The service in each of these categories requires caregivers with different skill levels. The daily living assistance can be performed by low skilled caregivers who may not have a qualified certification[8]. The social life assistance requires caregivers with a higher level of skills that can be only obtained through the training provided by some certified State institutions[9]. Finally, the essential acts of life require highly skilled caregivers who must have a State degree and a minimum of 6 months of experience[10]. In the home-care domain, the number of services that a client needs is usually variable week over week, depends on his/her health status and needs for social activities. Moreover, a service task generally requires only one caregiver, except for some special cases when several caregivers might be needed. These concern synchronized tasks in which several different services have to be provided simultaneously (Gayraud et al, 2015).

[7] https://www.service-public.fr/particuliers/vosdroits/F246
[8] http://www.una.fr/3849-S/agent-a-domicile.html
[9] http://www.una.fr/3850-S/employe-a-domicile.html
[10] http://www.una.fr/3851-S/auxiliaire-de-vie-sociale-avs.html

The descriptions of the two real problems in the service-to-business domain in Brazil and the service-to-individual in France, presented above, show us the basic differences between the characteristics of the client demands in these two service domains. Firstly, the daily and weekly demands are more stable in the service-to-business than in the service-to-individual domain. For each client, the number of tasks per day and their daily repetitiveness are usually not too different from week to week in the service-to-business domain, while these can be quite fluctuating in the service-to-individual domain. Secondly, businesses have much higher demands than individuals. A demand of a business, such as cleaning and surveillance services for a hospital or a shopping center, can require up to dozens of agents at the same time, 24h per day, 7 days per week; while an agent in the service-to-individual domain, such as home health care, conversely, can serve several clients per day. Then, the start and end times for tasks required by businesses are generally stricter than by individuals. For example, the start and end times of a surveillance service required by a supermarket are usually the same as the opening and closing hours of that supermarket; while a one-hour morning cleaning service required by a household can be performed at any time between 7 AM and 10 AM, agreed in advance between the company and its client. Finally, agent efficiency in the service-to-business domain generally depends more on their familiarity with the workplace than in the service-to-individual domain. Assigning an agent, who usually works in a shop, to a hospital makes it difficult for him/her to adapt quickly to the job that might affect the quality of service; while providing a home-care service to a client in the workplace A or B does not seem to affect his/her work efficiency. However, the service quality related to the clients' preferences for different agents is stronger in the service-to-individual domain than in the service-to-business domain. For example, an elderly or a vulnerable patient would prefer not to change their caregiver too often, while a supermarket client does not quite care if agent A or B performs his/her cleaning task on a given day as long as he/she is good at cleaning.

After the economic crisis in 2008, we have seen a high level of unemployment rate throughout the world, for example, 10.5% in France in 2015[11], 12.83% in Brazil in 2017[12]. Many countries have introduced labor law reforms in the hope of combating unemployment. In France, the Macron labor reform 2017[13] allows companies to hire agents with more flexible daily and weekly work

[11] https://www.insee.fr/fr/statistiques/4201123
[12] https://www.statista.com/statistics/263711/unemployment-rate-in-brazil/
[13] https://droit-finances.commentcamarche.com/faq/61943-reforme-du-code-du-travail-reforme-macron

schedules, especially for night and weekend shifts. In Brazil, the 2017 labor reform[14] allows the companies to use part-time agents with more variable numbers of work hours per day and workdays per week as well as a shorter contract duration. Using part-time agents, especially those with flexible start and end times per day and number of workdays per week, can help the company to save a lot of money by reducing the number of extra full-time agents who have been currently used to deal with fluctuating demands. The full-time agents are still commonly used because of their high loyalty that can ensure long-term workforce stability. However, in the short-term when client demands are fluctuating or in unexpected situations like sickness or unplanned leaves, part-time agents become more suitable. Companies are combining both of these two contract types to reduce the workforce costs, increase its flexibility in answering variable demand, and dealing with unexpected changes.

Labor law is only part of changes to which the company has to adapt. For international companies operating in many different countries, tax policy, basic salary, overall cost, transport system are different between countries or even between regions in the same country. Solving this problem at a country or region level seems to be difficult when considering all of these factors. The problem considered at these levels concerns the resources allocation in which the company's objective is to move and reallocate its resources from countries/ regions with redundant resources to countries/ regions with a shortage of resources in the long-term. The work team building and planning problem, which is more operational than the resource allocation mentioned previously, is usually solved at municipality or city levels in which agents' travel time is not too long in comparison to their real work time. In developed countries like France, Germany, or the United Kingdom where the transport infrastructure, especially public transport, is quite efficient and the travel time is short even between municipalities in the same region, living in a municipality and working in another one is not an impossible thing. However, in developing countries like Brazil, Vietnam, or India, even living in a part and working in another part of a city is sometimes difficult. It is often considered that a municipality has three zones in order of distance from the city center, including the urban, suburban, and rural. The distribution of clients' workplaces and agents' homes on these three zones, depending on each specific service domain, significantly affects agents' choice for the travel modes. For some service-to-individual sectors, such as health care and

[14] https://www.tmf-group.com/en/news-insights/articles/2018/november/brazils-labor-reform

tutoring, most of the clients and agents are widespreadly distributed in the urban zones. The agent travel mode is usually public transport or private means, using buses to transport agents to workplaces does not seem to be an economical way. For housework services or some services provided to hospitals, banks, schools, and shopping centers, most of the agents live in sub-urban zones while clients are widespread in the urban zones. The transport mode of agents is usually public transport if it is efficient between suburban and urban zones. Otherwise, private means are preferred. For some services for industries such as cleaning, concierge, or surveillance, industries are usually concentrated in small industrial zones in suburban or urban areas while most of the agents live in suburban or rural areas. If the transport costs between agents' homes and their workplaces are in charge by the company, using buses instead of public transport or private means may be a potential way to reduce the agents' travel costs.

1.2. Formulation of research questions

Given some stable or variable clients' demands and the company's human resources, we aim at finding the answers to several following research questions:

- How to identify and model all the demands and resources characteristics, their dependencies, as well as the decisions to assign the resources to the demands taking into account multiple constraints?
- How to reconcile economic and social performance criteria in planning?
- How to reconcile the assignment stability in the case of a regular demand with global optimization?
- How to increase the flexibility of resources to meet variable demand?
- When the demands and the resources vary from one planning horizon to another, how to manage the dependence of the work plans between the horizons?

1.3. Thesis outline

To answer these research questions, in Chapter II, we propose a generic class diagram to identify all the characteristics of the demands, the resources, and decision-making problems. This diagram is inspired by the two real problems found in Brazilian companies in the service-to-business domain and French companies in the service-to-individual domain, as well as an important literature analysis on these two problems. Each instantiation of the diagram results in a problem variant corresponding to a combination of decision-making, levels of demand variability, levels of flexibility of resources, and economic or social performance indicators. Chapter III completes the characterization of the generalized problem of Chapter II with a quantitative analysis of the literature review. In-depth analysis allows us to identify in particular potential organizational levers to increase the flexibility of resources. Chapters IV and V examine two variants of the problem, inspired by the problem of the Brazilian company in the service-to-business domain, in two different contexts. Chapter IV considers the problem in the context of stable demand, which corresponds to the company's current situation. Several agents' work contracts corresponding to different daily and weekly capacities are considered. We propose a two-level multi-criteria planning approach: weekly planning repeated for each set of new customers and, at a lower frequency, re-planning for all active clients allowing global optimization. This approach allows us to ensure a compromise between the company's economic performance and agents' satisfaction, as well as assignment stability while taking into account new clients' demands. Chapter V considers the problem in a context of variable demand, which is an "expected future" for the company. We specify some organizational levers, including the uses of flexible work contracts, multi-skilled agents, and additional agents' work hours, and assess their impact on the problem. Besides, we propose a new approach to model the dependence between the planning horizons "dependent with buffer zones", which is an intermediate between the independent and "fully" dependent; the first is a classic approach but is not very realistic; the second corresponds to a realistic industrial approach but it is too constrained. Finally, in Chapter VI, we give conclusions and perspectives for future research.

Chapter II. Problem characterization

Résumé en français

Dans ce chapitre, nous proposons trois approches différentes pour caractériser le problème de la constitution et de la planification d'équipes de travail. Ces trois approches sont principalement inspirées par les deux problèmes réels dans les domaines du service aux entreprises et du service aux particuliers (voir Section 1.1), et une analyse bibliographique importante de ces deux problèmes. La première approche (section 2.1) considère les quatre sous-problèmes de prise de décision (affectation d'agents, constitution d'équipes, planification d'activités, et tournées de véhicules) et leurs combinaisons. Se concentrer uniquement sur un ou deux sous-problèmes principaux et utiliser les techniques de décomposition peut aider à réduire considérablement la complexité du problème. Par exemple, la constitution d'équipes peut être considérée comme le résultat de l'affectation d'agents lorsqu'une équipe correspond à un groupe d'agents affectés à la même tâche. Le problème de tournées des véhicules peut également être décomposé en supposant qu'un agent ne peut effectuer qu'un maximum d'une tâche par jour et qu'aucun routage entre les lieux de travail n'est pris en compte pour les agents. De plus, on peut supposer qu'il / elle utilise les transports publics pour se déplacer entre le domicile et le lieu de travail ; aucune tournée de véhicules pour chercher les agents chez eux et les transporter sur leur lieu de travail n'est considérée. La deuxième approche (section 2.2) caractérise le problème à travers les cinq classes d'objets qui incluent les agents, les clients, les tâches, les trajets et les véhicules. Cette approche de caractérisation permet d'identifier et de structurer les données qui seront ensuite utilisées pour la modélisation et la résolution du problème. Elle permet en outre d'identifier les indicateurs de performance qui seront ultérieurement utilisés comme objectifs. La troisième approche (section 2.3) correspond au point de vue des entreprises, et caractérise le problème par différents niveaux de variabilité de demande et différents niveaux d'adaptation des agents. Chaque niveau de variabilité de demande nécessite un certain niveau d'adaptation des agents.

Ces trois approches de caractérisation ont montré que le problème de constitution et planification d'équipes de travail comporte un grand nombre de variantes avec différents niveaux de complexité. Chaque variante correspond à une combinaison d'un certain nombre de problèmes

de prise de décision, d'un certain nombre de caractéristiques des cinq classes d'objets associés au problème, d'un certain nombre d'indicateurs de performance, et enfin d'une combinaison d'un niveau de variabilité de la demande et d'un niveau d'adaptation des agents.

In this chapter, we present three different approaches to characterize the work team building and planning problem. The first approach (section 2.1) is based on the four decision-making sub-problems that companies have to deal with that are agent assignment, team building, activity planning, and vehicle routing. Depending on the number and types of decision-making problems considered which significantly affect the complexity of problem solving, different modeling and solving methods can be used. The second approach (section 2.2) characterizes the problem by five classes of objects: the clients, the tasks, the agents, the travel routes, and the vehicles. This second characterization approach helps to identify and structure the data that will be later used for problem modeling and solving. It helps moreover identify the performance indicators that will be later used as the objectives. The third approach (section 2.3) corresponds to the business point of view and characterizes the problem by different levels of demand variability and different levels of workforce adaptation. Each type of demand requires a certain workforce structure and for each demand variability, a workforce with a certain adaptation should be considered. Moreover, for each demand variability, different methods with different levels of complexity might be used to model and solve the problem. These three characterization approaches are mainly inspired by the two real problems in the service-to-business and service-to-individual domains (see Section 1.1), and an important literature analysis of these two problems. A preliminary version of the first and second characterization approaches gives the materials for a conference paper (Doan, Fondrevelle, and Botta-Genoulaz 2017).

2.1. By decision-making problems

The work team building and planning problem can be regarded as an integration of four common decision-making problems in operational research: agent assignment, team building, activity planning, and vehicle routing problems. Solving these four problems corresponds to answering the four following questions respectively: Who will do what? Who will work with whom? When will they start their jobs? Finally, how will they go to their workplaces?

2.1.1. Agent assignment problem

Agent assignment problem is the problem of assigning a set of agents to a set of tasks (Morales and Romeijn, 2004). Each task is performed by exactly one agent and each agent-task assignment incurs a cost and needs a certain quantity of resources (agent work time, equipment, material, etc.). The objective is usually to minimize the costs while ensuring the constraints of resources budgets. (Morales and Romeijn, 2004) present some common extensions of the agent assignment problem. (Srinivasan and Thompson, 1972) considers an extension in which agents' capacity can increase at a certain cost, being linear in the amount of added capacity. The fixed-charge extension considers that each agent has a fixed cost when he/she performs at least one task (Neebe and Rao, 1983). The multi-resource extension considers that tasks can consume several resources at the same time (Gavish and Pirkul, 1991). This is extended to another version called multi-level generalized assignment problem where agents can process tasks with different levels of efficiency (Glover et al., 1979). An extension of this problem supposes that tasks may need to be simultaneously performed by more than one agent to increase its reliability (Park et al., 1998) or that tasks can be split over different agents (Kogan et al., 1997).

2.1.2. Team building problem

Team building problem is the problem of organizing agents into teams to perform tasks together. Even considered as one of our four decision-making problems, the team building problem is not studied individually, it is always considered together with the agent assignment problem in which agents are organized into work teams and teams are assigned to tasks (Eveborn, Flisberg, and Ronnqvist, 2006).

(Thiel et al, 2008) defines a team as a group of different crewmembers with, if required, different crew functions (captain, first officer, cockpit, cabin, etc.) and quantities. The objective concerns the cost minimization for the airline and maximization of quality-of-life criteria for the crew such as the preferences of a member for working/ not working with some specific colleagues, or at the weekends or during the vacations. When assigning agents to teams, we sometimes have to take into account the team size, and the work regulations related to the maximum agent workload per day and week, and the workload balance between them.

2.1.3. Activity planning problem

Activity planning problem is the problem of setting the start time for each activity to fulfill the greatest possible number of activities. This problem exists when some of the activities can start and end within the time windows that are larger than their durations. However, similarly to the team-building problem, the activity-planning problem is not considered individually but always together with the agent assignment problem, in which performing an activity always needs some resources (agents, machines, or materials). This combination is often called the workforce-scheduling problem. A literature review on this problem can be found in (Pinedo, 2005). (Pinedo, 2005) presents that, the cyclic staffing problem is a classical variant of the workforce scheduling problem, in which the objective is usually to minimize the costs to assign agents to a cyclic schedule of a certain number of periods so that sufficient agents are present in each period and each agent works a shift of several consecutive periods. Some extensions of the cyclic staffing problem are the days-off scheduling, the cyclic staffing with overtime, and the cyclic staffing with linear penalties for understaffing and overstaffing. The days-off scheduling considers that each agent is guaranteed two days off a week and is not allowed to work more than 6 days consecutively. The cyclic staffing with overtime allows a certain additional number of hours for each shift. Finally, the cyclic staffing with linear penalties for understaffing and overstaffing supposes that the demands for each period are not fixed, and understaffing and overstaffing can occur but with a certain cost.

2.1.4. Vehicle routing problem

Vehicle routing problem is the problem of setting routes for a fleet of vehicles to deliver products or services to customers (Irnich, Toth, and Vigo 2014). The travel cost/time depends on the arcs (routes) that we choose for each vehicle (see Figure 2). In our study, vehicles carry agents to clients’ sites to provide requested services. The objective is usually to minimize the total travel costs/ times while meeting client demands, as well as agents’ satisfaction (wish to spend less time traveling).

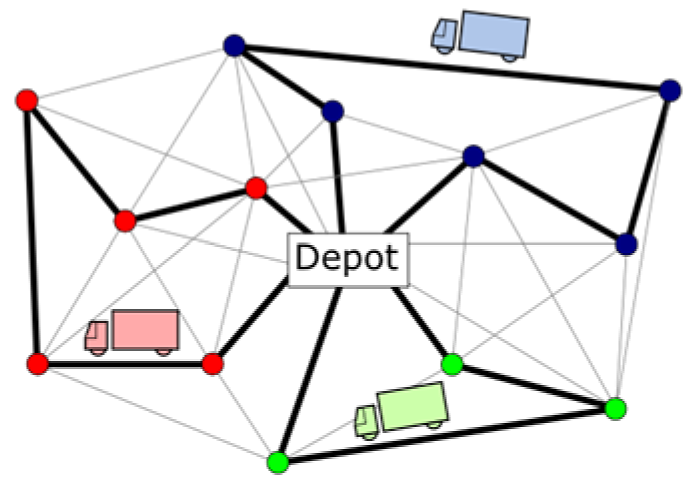

Figure 2. Example of a vehicle routing problem with thirteen clients and three vehicles

(Irnich, Toth, and Vigo 2014) present some important variants of the vehicle routing problem related to the transportation of people from one place to another place. In terms of transportation requests, the two common variants are the pickup-and-delivery and vehicle scheduling problems. The pickup-and-delivery problem considers that goods/passengers need to be moved from certain pickup locations to delivery locations. This problem, in the context of passenger transportation, is known as the Dial-a-Ride problem in which pupils, patients, and handicapped and elderly people are transported between their homes and schools, care facilities, or hospitals (Irnich, Toth, and Vigo 2014). For the vehicle-scheduling problem (Desrosiers et al., 1995), the service is neither collection nor delivery but merely consists of visiting a customer or location. For example, service technicians repair or install a machine, and nurses take care of elderly people at their homes (Irnich, Toth, and Vigo 2014). In terms of constraints, a first variant is the capacitated vehicle routing problem which considers that each vehicle has a limited carrying capacity (Laporte, Nobert, and Taillefer 1987). Another variant is the vehicle routing problem with time windows, which considers a time interval within which the deliveries have to be done (Cordeau et al, 2002). The stochastic vehicle routing problem considers random variables caused by the demand fluctuation, vehicle breakdown, or long travel time due to congestion (Bertsimas et al, 1992). The dynamic vehicle routing problem considers the variability of the system, such as customers' locations and demands over time (Tillman et al, 1969).

2.1.5. Combinations of decision-making problems

The combination of two, three, or all of these four decision-making problems can create many different problem variants. However, for the problem under study within this Doctoral thesis, the agent assignment problem is the core decision-making problem; we only consider the combinations between this problem and the other problems. For such combinations, we first have three combinations of the agent assignment problem with each of the other three:

- The agent assignment and team building problem is often called the team/crew/staff scheduling/planning/assignment problem (Firat, Briskorn, and Laugier 2016).
- The agent assignment and activity planning problem is often named as the personnel/workforce/manpower scheduling/planning/assignment problem with time windows/time-dependent constraints (Alsheddy and Tsang 2009; Borsani et al. 2007; Ogulata, Koyuncu, and Karakas 2008).
- The agent assignment and vehicle routing problem is often called the personnel/workforce/nurse routing problem (Cappanera, Gouveia, and Scutellà 2013).

For combinations between three decision-making problems, we have three different cases, including agent assignment, team building together with one of the other two, and finally between these two with the agent assignment problem.

- The agent assignment, team building, and activity planning problem is often called the team/crew/staff planning/scheduling problem with time windows/time-dependent constraints (Cordeau et al. 2010; Dohn, Kolind, and Clausen 2009; Rocha, Oliveira, and Carravilla 2013).
- The combination of agent assignment, team building, and vehicle routing problems without the activity-planning problem is rarely found in the literature.
- The combination of agent assignment, activity planning, and vehicle routing problems is often found with the name as the personnel/workforce/nurse rostering/routing (and scheduling) problem with time windows/time-dependent constraints (Bredström and Rönnqvist 2008; Cappanera, Gouveia, and Scutellà 2011; Chen, Thomas, and Hewitt 2016).

Finally, the most complex problem, the combination of all these four decision-making sub-problems, is often named the team/crew routing (and scheduling) problem with time windows/time-dependent constraints (Kim, Koo, and Park 2010; Kovacs et al. 2012; Laurent et al. 2015). Because the team building can only appear together with the agent assignment problem, its number of combinations with others is less than those of the other three.

2.2. By classes of objects associated with the problem

In this section, we study the problem characteristics through its five classes of objects: the clients, the tasks, the agents, the travel routes, and the vehicles. This characterization approach is not independent of the first approach, which is based on decision-making problems. Each decision-making problem is characterized by some attributes of these five classes of objects. The relation between these two approaches will be introduced in Section 2.2.6. Most of the characteristics of the five classes of objects considered in this section are coming from the real problems found in the service-to-business domain in Brazil and the service-to-individual in France. The remaining characteristics are classical characteristics that have been commonly studied in the literature. We generally consider a planning horizon of several days (D). A day is an intermediate time unit and each day is divided into several periods (T), which can be, for example, four hours.

The characteristics of each of the five classes of objects are explicitly presented in Figure 3:

2.2.1. Client

Client is a person or an organization that uses the services of the company. Below are the characteristics we consider for each client.

- Client ID: each client is identified by a client ID, numbered from 1 to P.
- Client address: is the address of a client where his/her tasks are performed. Each client is considered to have only one address, which is located by its GPS coordinates. If a person or organization has several addresses, each address is considered to attach to a different client.
- Preferences for service periods: is the desire of a client to be served at several specific periods of the day or on several specific days in the week.

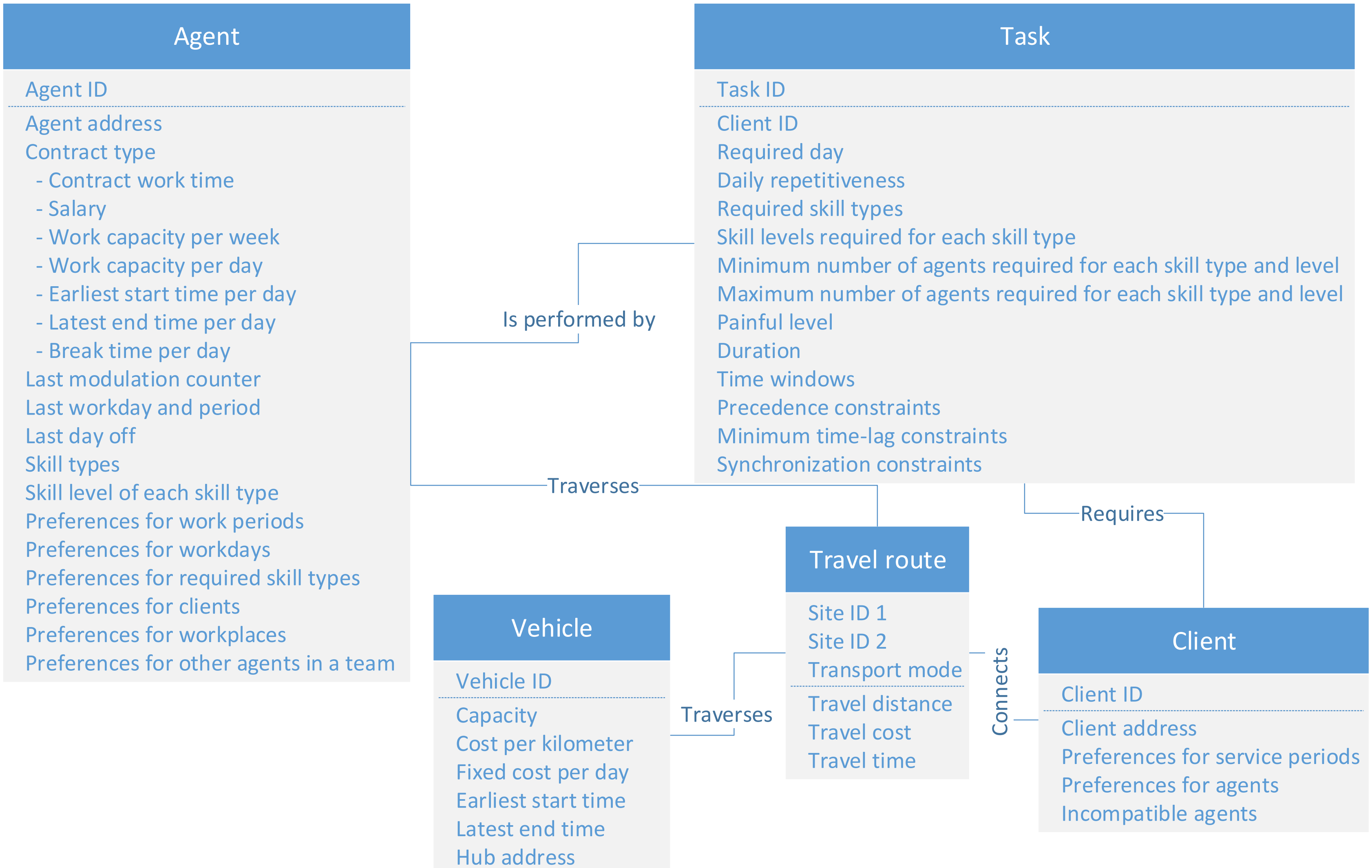

Figure 3. Class diagram for the work team building and planning problem

- Preferences for agents: is the desire of a client to be served by several specific agents. The clients' preferences for agents or service periods presented above are assumed to take one of these three values: -1: dislike, 0: neutral, +1: like.
- Incompatible agents: are the agents who are not compatible with the client and therefore, cannot be assigned to his/her tasks.

2.2.2. Task

The company provides its services to clients under service contracts, also called demands. Each demand is mainly characterized by the duration of this service contract, a weekly and daily repetitiveness, a daily duration, and time windows. For example, a one-year contract with the same demand every week, 6 days per week from Monday to Saturday, 8 hours per day between 8 am and 4 pm. This demand is divided into tasks that are then assigned to the agents. The task is the smallest work unit that we consider and most of its characteristics are the same as those of the corresponding demand. Below are the characteristics we consider for each task.

- Task ID: each task is represented by a task ID, numbered from 1 to J.
- Client ID: is the ID of the client who requires the task.
- Required day: is the day on which the task is required. Days of the planning horizon are numbered from 1 to D. In most of the cases, the horizon considered is a week with seven workdays.
- Daily repetitiveness: This characteristic only makes sense when the demand is not punctual, which means that the task can be repeated on several different days of the planning horizon.
- Required skill types: are a list of skills (K) that agents must have to be able to perform the task. In the service-to-individual, technical skill types such as health care or tutoring, are usually considered. In the service-to-business domain, because agents usually work in a team, besides the technical skills, managerial skills such as teamwork and leadership are also required.
- Skill levels required for each skill type: For each skill type, the task may need agents who have different skill levels. Required skill levels are usually related to the experience that an agent needs to be able to fulfill the task efficiently. The number of skill levels (Q) can,

therefore, differ in different domains. For example, companies in the service-to-individual domain usually consider five technical skill levels: 0: not acquired, 1: ongoing acquisition, 2: acquired, 3: mastery, 4: tutor. An agent with level 0 cannot be assigned to any task. An agent with level 1 cannot perform a task alone; he/she needs to be tutored by an agent with level 4 for a certain duration of time before attaining level 2 and being able to perform tasks alone. An agent with level 3 can perform a task easily and with high quality. A tutor has a skill level as high as an agent with level 3 and a capability of tutoring an agent with level 1. By contrast, for some companies in the service-to-business domain such as the Brazilian company that we are working with, three managerial levels are considered: level 0 (normal worker), level 1 (leader of several normal workers), and level 2 (supervisor of several leaders). Generally, depending on the importance of a task, the company determines, agreed with its client, the minimum skill level an agent must have to be able to perform the task. Moreover, because some agents may prefer performing a task requiring the same skill level he/she has, some companies assign an agent to a task only when this task requires the same skill level as what the agent has. For example, an agent with skill level 3 is only assigned to a task requiring skill level 3, not the one requiring skill level 2, 1, or 0.

- Minimum number of agents required for each skill type and level: for each skill type and level, the task needs a minimum number of agents. To start the task, all these agents have to be simultaneously present at the task's workplace.
- Maximum number of agents required for each skill type and level: for each skill type and level, the number of agents assigned to a task should not exceed a certain number of agents.
- Painful level: is related to tough working conditions such as hot, noisy or polluted, or the nature of the task such as long duration or being required at night or early in the morning.
- Duration: is the amount of time that all the required agents must spend to perform the task. It is continuous, indivisible, and not too long to be able to start & end on the same day. The task duration is assumed not to depend on either the number of agents performing it or their skills.
- Time windows: refers to a time interval of a day within which a task has to start and end. Because the time windows for a task in the service-to-business domain usually depend on many constraints (client's organization, client's production plan, etc.), tasks can only be performed in a fixed time interval. The time-windows constraint is, therefore, usually considered as a hard

constraint for critical tasks, which has to be strictly met. However, for less critical tasks, this can be seen as a soft constraint where any violation has to be compensated by a penalty.

- Precedence constraints: are time constraints between two tasks in which a task can only start if the other is already terminated. These constraints should be only imposed on two tasks of the same demand required by a client.
- Minimum time-lag constraints: are time constraints between two tasks in which a task has to terminate a certain amount of time before the start of another. These constraints can be considered as an extension of the precedence constraints (Fondrevelle, Oulamara, and Portmann 2008) that should be only imposed on two tasks of the same demand required by a client.
- Synchronization constraints: are time constraints between two tasks that force them to start and end at the same time. These constraints should be also imposed on two tasks of the same demand required by a client.

2.2.3. Agent

An agent is a person who works for the company. Each company has a list of available agents to perform tasks. Here are the agents' characteristics that we consider:

- Agent ID: Each agent is represented by an agent ID, numbered from 1 to N.
- Agent address: is the agent's home address from which he/she leaves for work. Each agent is considered to have only one address, which is located by its GPS coordinates.
- Contract type: is the contract signed between the agent and the company specifying his salary, monthly work time, number of workdays per week, number of work times per day, daily start, end and break times, etc. These terms, regulated by the labor law, have to be strictly met when creating work plans for agents. An agent contract can be shift or non-shift, full-time or part-time, permanent or temporary, regular or flexible. A shift contract has a variable daily work schedule in which the work and break times are periodically repeated; while a non-shift contract always has the same start and end times every workday except days off. A full-time contract, depending on the country, usually works between 35 and 48 hours per week and get some benefits besides the salary, while a part-time contract usually works less than 30 hours per week, depending on the company's needs and the labor law of each country. A full-time or

part-time agent is a permanent agent of the company while a temporary agent is not; he/she only has a fixed-term work contract with the company. A temporary agent usually has a higher salary per hour than a permanent agent for the same job to compensate for the insecurity of the contract. However, these agents usually do not have other benefits different from their salaries like a permanent agent such as health care or unemployment insurance. An agent with a flexible contract usually has very flexible start and end times, a flexible number of work hours per day and number of workdays per week in comparison to regular agents (Stolletz 2010). A casual contract is both a temporary and flexible contract. Depending on the labor law of each country, such as France[15] and the UK[16], this casual contract may only exist in some business sectors and have some specific labor rights. In our study, the planning horizon usually refers to a week with seven days, and each day is divided into several periods of several hours.

- ✓ Contract work time: is a basic duration that an agent has to work per week or month; the work time beyond this duration is considered as overtime. The contract work time can be different between agents.
- ✓ Salary: is the amount of money that an agent is paid. This amount depends on his/her profile (skills, work experiences, etc.) and the job that he/she is hired for.
- ✓ Work capacity per week: is the maximum agent's work time per week, including overtime.
- ✓ Work capacity per day: is the maximum agent's work time per day, including overtime. The work capacity per week is usually smaller than the work capacity per day multiplied by the maximum number of workdays per week.
- ✓ Earliest start time per day: is the earliest time that an agent can start working at a client site on a day. It is later than the start service time of the company and can be different between workdays.
- ✓ Latest end time per day: is the latest time that an agent should finish working at a client site on a day. It is earlier than the end service time of the company and can be different between workdays.
- ✓ Break time per day: is the minimum amount of time needed for an agent to rest between two consecutive tasks or in the middle of a long task. Lunchtime is an important type

[15] https://www.service-public.fr/professionnels-entreprises/vosdroits/F33693
[16] https://www.gov.uk/employment-status/worker

of break time. This time can be fixed (between noon and 1 pm) or flexible (1h between 11 am and 3 pm) but has to be taken into account when defining agents' work plans.

- Last modulation counter: Because the agent's real work time on a planning horizon can be different from his/her contract work time, a modulation counter is used to measure the accumulation of these differences on many consecutive planning horizons. This counter equals the sum of the difference between the agent's real work time and contract work time on the current horizon and his/her last modulation counter on the previous horizon. This counter can be, therefore, negative, positive, or zero. A positive (resp. negative) value means that the sum of his/her real work time on the current horizon and his/her last modulation counter is greater (resp. smaller) than his/her contract work time. A zero value means that they are equal. Agents' modulation counter on this horizon will become the last modulation counter when considering the next horizon. If an agent just starts his job on this horizon, his last modulation counter equals zero.
- Last workday and period: are the last real workday and period of the agent in the previous planning horizon. These two characteristics are considered only for shift agents whose contract is not defined per week and the end time of the last activity can vary between different periods of a day and several possible days of the week. For example, an agent of the 12x36 contract (see Section 5.2.2.3) has a work and break cycle of 12 hours and 36 hours, and his/her contract is, therefore defined per 2 days. His/her last workday and period on a horizon of 1 week can be day 6 or 7 and in the afternoon, evening, or at night, depending on his/her first workday and period of the week.
- Last day off: is the last day-off of the agent in the previous planning horizon. This characteristic is considered only for non-shift agents whose work periods are the same every day. For example, an agent with a 5x2 contract (see Section 5.2.2.3) who works 5 consecutive days and has two consecutive days off per week, can work from day 1 to day 5, day 2 to day 6 or day 3 to day 7 and therefore, his/her last day off can be day 5, 6 or 7. This characteristic and the two characteristics above allow considering the dependence of agents' availabilities between consecutive planning horizons. However, if the agent is newly recruited for this planning horizon, he/she does not have the last workday and period or the last day off.

- Skill types: are types of skills that an agent has. An agent can have one or several different skill types. An agent can perform a task only when he/she has the skill type that the task requires (see Section 2.2.2).
- Skill level of each skill type: is the skill level for each skill type that an agent has. The skill level for each skill type is evaluated regularly by the company and fixed for a certain duration. Each agent skill level corresponds to a required skill level for each skill type of a task (see Section 2.2.2). An agent can have several different types of preferences as below. We assume that agents' preferences take one of the three following values: -1: dislike, 0: neutral, +1: like.
- Preferences for work periods: agents may prefer working at certain periods of the day.
- Preferences for workdays: agents may prefer working on certain days of the week if his/her work contract allows.
- Preferences for required skill types: agents may prefer using some of his/her skill types at which he/she is good to perform tasks.
- Preferences for clients: agents may prefer working with some clients to others.
- Preferences for workplaces: agents may prefer working at some workplaces, usually the closest to his/her home or school of his/her children.
- Preferences for other agents in a team: agents may prefer working with some specific agents, for example, the ones he/she already knows.

2.2.4. Travel route

Travel route is the road connecting an agent/ a client/ a transport hub site to another agent/ client/ transport hub site. For a specific vehicle type (bus, private car, or public transport), we assume that a unique road exists between any two sites. Below are the characteristics considered:

- Site ID 1: is the ID of the start point of the route, which can be a hub, an agent, or a client address.
- Site ID 2: is the ID of the endpoint of a route, which can be a hub, an agent, or a client address.
- Transport mode: is the vehicle type that an agent uses to travel routes such as bus, private car, or public transport. This characteristic is considered only if several transport modes exist between two points.

- Travel distance: is the road distance between the two sites ID1 and ID2, with the given transport mode.
- Travel cost: is the road travel cost between the two sites ID1 and ID2, with the given transport mode.
- Travel time: is the road travel time between the two sites ID1 and ID2, with the given transport mode.

2.2.5. Vehicle

Agents can use different transport means to travel between their home and workplaces such as a shuttle, a private car, or public transports. For the problem under study, this class only makes sense if the vehicle (usually a bus) is managed by the company, which exists only in certain countries or service sectors. In such a case, the vehicle characteristics are as below:

- Vehicle ID: each vehicle is represented by a vehicle ID, numbered from 1 to V.
- Capacity: is the maximum number of agents that the vehicle can carry. Each vehicle can have a different capacity.
- Cost per kilometer: is the cost that incurs when the vehicle is used, such as fuel costs.
- Fixed cost per day: is the cost that the company has to pay even when the vehicle is not used (depreciation, vehicle maintenance, driver salary, etc.)
- Earliest start time: is the earliest time that a vehicle can be used, for example depending on the earliest work time of the driver.
- Latest end time: is the latest time that a vehicle can be used, for example depending on the latest work time of the driver.
- Hub address: is the location where the vehicle starts and ends its trips.

2.2.6. Characterization approach based on the classes of objects

2.2.6.1. Classes of objects and decision-making problems

The agent assignment problem is the core decision-making problem of the work team building and planning problem. We only consider the variants of the problem that correspond to the combinations between this problem and one, two, or three other problems. Each decision-making problem can be characterized by some characteristics of several classes of objects. Adding or removing a characteristic will create a new problem variant. Table 1 presents the characteristics of each class of objects that have to be considered for each combination of decision-making problems. Row 2 presents the agent assignment problem with its characteristics. Each time we add another decision-making problem to the agent assignment problem (following rows), we specify the new characteristics to take into account additionally for the new problem.

2.2.6.2. Classes of objects and performance indicators

In the context of economic and social performance, companies have to take into account the benefits of different stakeholders in the planning process, which include the company itself, the clients, and the agents. The company often wants to reduce the overall costs and maximize its profits. The clients require their services to be delivered on time and with high quality. Moreover, their preference satisfaction, for example, for some specific agents, should be respected. Agents are generally seen as the company's "resources" and their satisfaction is considered as a social performance criterion. Therefore, we present here three common categories of objectives: the company costs, the clients' and agents' satisfaction. To explain these performance indicators, we use the characteristics of the five classes of objects presented previously.

Overall costs

The two most important components of the overall costs are transport and agent assignment costs. The transport costs include fixed transport costs such as vehicle depreciation and maintenance costs, and variable transport costs such as fuel costs and traffic charges. Assignment costs are associated with the workforce needed to fulfill the required tasks. The assignment costs are ideal when all the agents are permanent (full-time and part-time but not temporary), the number of agents' work hours for each skill type and level exactly equal to those required by the tasks, and no overtime is, moreover, needed. However, in reality, the number of available permanent agents for each skill level and type at each period is limited, a task may be assigned to a permanent agent with more-than-necessary skills or a temporary agent instead of a permanent agent. These are additional assignment costs because agents with higher qualifications (respectively with temporary contracts) are usually paid more than those with lower qualifications (respectively with permanent contracts). Besides, overtime is sometimes needed, especially when the demand highly fluctuates.

Table 1. Characteristics of classes of objects for decision-making problems' combinations

Object /Problem	Clients	Tasks	Agents	Travel routes	Vehicles
Agent assignment problem	- Client address - Preferences for agents - Incompatible agents	- Required skill types - Skill level required for each skill type - Painful level	- Agent address - Skill types - Skill levels of each skill type - Preferences for required skill types - Preferences for clients - Preferences for workplaces	- Travel distance - Travel cost	
+ Team building problem		+ Minimum number of required agents for each skill type and level + Maximum number of required agents for each skill type and level	+ Preferences for other agents in a team		
+ Activity planning problem	+ Preferences for service periods	+ Required day +Daily repetitiveness + Duration + Time windows + Precedence constraints + Minimum time-lag constraints + Synchronization constraints	+ Contract type (earliest start time, latest end time, break time) + Last modulation counter + Last workday and period + Last day off + Preferences for work periods + Preferences for workdays	+ Travel time	
+ Vehicle routing problem					+ Capacity + Cost per kilometer + Fixed cost per day + Earliest start time + Latest end time + Hub address

Clients' satisfaction

Clients' satisfaction is related to the fulfillment of the clients' demands and the respect of their preferences. The demand fulfillment concerns the on-time service requirement, the compatibility between agents' skills and those of the required service, and the service quality. Companies generally want to ensure all the demands to be fulfilled correctly and they do not lose their clients to competitors. The clients' preferences refer to the clients' desires to be served by some specific agents or groups of agents that they know well or to be served in a certain period of the day or on a certain day in the week. This happens quite often in the domain of home care or maintenance, where the relationship between an agent and a client is quite close.

Agents' satisfaction

Agents' satisfaction refers to the workload balance between agents and the respect of their preferences. Workload balance is the balance of the workload between agents on a horizon (week, month, or year) (Gruat-La-Forme, Botta-Genoulaz, and Campagne, 2007). It can be assessed through the difference of the numbers of work hours between agents or the gap between the agents with the largest and the smallest differences between their real work hours and contract work hours. The larger these differences/gaps are, the less balanced the agent workload is. In a company, agents usually have a work contract specifying their basic number of work hours per week or month (for example 8 hours per day and 5 days per week). However, it is hard to ensure that this duration is the same for all the agents with the same contracts. Agents with higher skills who can fulfill most of the tasks are usually fully loaded. Balancing the workload among agents is an important objective that helps keep talented agents and ensure their long-term working ability. Besides the total number of working and travel hours per week or month between agents, balancing the number of work hours for painful tasks or the number of extra hours is also important to increase agents' satisfaction. The workload balance is often modeled as an objective. However, it can be also considered as a constraint where the number of work hours of each agent has to be within an interval or the difference between the workload of any two agents has to be smaller than a certain number of hours.

Agents' preferences refer to the fact that some agents prefer working with other specific agents in the same team, being assigned to some desired tasks, in certain periods of the day, or at some specific workplaces near their home to reduce their work trip duration. Ensuring the agents' preference satisfaction is important for the company. First, when their preferences are satisfied, they are more likely to stay with the company. Otherwise, they search for another job that can satisfy them better. For example, agents with children may prefer working in the daylight to in the evening or at night. They usually have to bring the children to school in the morning and pick them up at school in the afternoon. Besides, the agents' satisfaction affects their efficiency at work. Assigning two agents who do not like working with each other to the same team will reduce their efficiency especially when the task needs strong communication between them.

2.3. By demand variability and workforce adaptation

In each service domain and each territorial level, the client demand has different variability. Because the company workforce is built on demand, the more variable the demand is, the more flexible the workforce must be.

2.3.1. Demand variability

Clients' demands can be stable or variable over time. In the case of stable demand, the demand is the same on any planning horizon (Carter and Lapierre 2001; Millar and Kiragu 1998). By contrast, when the demand is variable, the demand on each planning horizon can be different from others (Avramidis et al. 2010; Cordeau et al. 2010; Stolletz and Zamorano 2014).

2.3.1.1. Stable demand

The demands are found stable in some situations. First, when each client is large and their demand is stable over an important number of planning horizons (weeks). This number usually depends on the contract duration between the client and the company. Therefore, when the total number of clients is stable over time, the total demand of all the company's clients are also stable (Naderi and Kilic 2016). In some situations, even when the total number of clients, including the current and new clients, changes over time, the total demand considered for each planning can also be stable. This happens when companies divide their clients into smaller groups to manage separately. Each group has a fixed number of clients who arrive in the same time span. The demand of each group is, therefore, stable for a certain long duration. The Brazilian company that we are working with is managing clients' demands in this way. Another situation is when the demand of each client can be variable but the total demands of all the clients are stable. This can be found, for example, in the health care domain in a hospital where the number of caregivers (or the hospital capacity) is fixed for a certain long duration and can only cover a limited number of care demands. The demands beyond the limit will not be accepted and transferred to other hospitals in the region (Rosenbloom and Goertzen 1987).

2.3.1.2. Variable demand

There are many reasons why demand is variable. First, the demand goes up and down periodically and seasonally, for example, higher demand for cleaning services for shopping centers at the weekends than on weekdays, or higher demand in summer than in winter. Next, this is due to occasional events such as maternity leave (Azmat, Hürlimann, and Widmer 2004). Then, some unexpected events like disasters and epidemics can fluctuate the demand, for example, a very high demand for home or "Drive" delivery service of the Carrefour supermarket during the Covid-19 pandemic in France[17]. Finally, when most of the clients have one-time demands without daily and weekly repetitiveness, the total demands of all these clients, therefore, vary widely (Avramidis et al. 2010).

Table 2. Example of demand variability

Type of demands Factor considered	Basic (or stable) demand	Moderately variable demand	Widely variable demand
Number of required days per week	5 days	6 days	3 days
Specific required days per week	Monday – Friday	Monday-Saturday /Tuesday-Sunday	Monday, Wednesday, and Saturday
Daily start and end times (5 days)	8 AM-5 PM every day	8 AM-5 PM 4 days, 9 AM-4 PM 1 day	8 AM-8 PM Monday and Saturday, 4 AM-2 PM Wednesday
Daily duration (5 days)	8 hours every day	8 hours 4 days, 6 hours 1 day	11 hours on Monday and Saturday, 9 hours on Wednesday
Number of agents required each day (5 days)	2 agents every day	2 agents 4 days, 3 agents 1 day	2 agents on Monday, 5 agents on Wednesday, 3 agents on Saturday

[17] https://france3-regions.francetvinfo.fr/auvergne-rhone-alpes/coronavirus-services-drive-livraisons-domicile-forte-hausse-1797594.html

The demand variability can be considered through the difference between the demand and a basic demand (or a forecasted demand). This difference can be moreover evaluated through some factors such as the differences in the number of required days per week, the specific required days per week, the daily start and end times, the daily duration, and the number of required agents per day between the considered demand and the basic demand. The larger the number of these factors is and the more different they are in comparison to those of the basic demand, the more variable the considered demand becomes. We give an example to show how these factors may affect demand variability (see Table 2). The demand variability affects the way to model the tasks, the definition of the planning horizon, and the planning frequency. A demand without variability can be modeled as a weekly demand with its repetitiveness over month or year. A variable demand needs to be analyzed more precisely to be modeled.

2.3.2. Workforce adaptation

Workforce adaptation is often considered through the five levers: the availability of different contract types, the use of flexible contracts, the use of multi-skilled agents, of extra agents, and of agents' extra hours.

2.3.2.1. Availability of different contract types

Each work contract has advantages and disadvantages. In terms of contract duration and work capacity, the three most common contracts are full-time (Azmat, Hürlimann, and Widmer 2004), part-time (Akbari, Zandieh, and Dorri 2013), and temporary contracts (Bard 2004) (see Section 2.2.3). Full-time agents are quite loyal to the company and considered as a stable workforce for the long term. However, when the demands are low and they do not have much work to do, they are also fully paid. Part-time agents normally have fewer work hours per week than the full-time, for example, 48 hours for the full-time (6 days per week, 8 hours per day) and 24 hours for the part-time. Two part-time agents working together can, therefore, replace a full-time agent in terms of workload. Moreover, the combinations between these two agents can fulfill the tasks that a full-time agent cannot do. For example, a task requiring 1 agent for 3 days per week and 16 work hours per day can be split into two smaller tasks of 3 days per week and 8 hours per day and assigned to two part-time agents. Therefore, part-time agents are generally more flexible than full-time agents. However, if the part-time is not from their initiative, they are generally less loyal to the company than the full-time agents. Different from full-time or part-time agents who are permanent agents and paid monthly, temporary agents are paid according to the number of hours that they work for a specific job. These agents are, therefore, the most flexible and cost-effective contracts among the three and thus used more and more to deal with unexpected situations like the sickness and accident or fluctuating demands in the short-term. However, they are generally not quite loyal to the company and using too many of these agents can affect the workforce stability.

In terms of daily work schedules, we have the shift (Laporte and Pesant 2004) and non-shift (or regular) agents (Azmat, Hürlimann, and Widmer 2004). Non-shift agents have a fixed daily work schedule that is 8 hours per day, usually from morning to late afternoon, and for 5 or 6 days per week. These agents are quite suitable for regular demands that can be widely found in different service sectors. By contrast, shift agents do not have a fixed daily work schedule and their work and break times are usually cyclic for example, 12 work hours, 36 break hours, and then again, 12 work hours. Shift agents are generally used more for long-duration tasks that can last until late evening or throughout the night, for example, 12-hour or 24-hour tasks, 7 days per week.

2.3.2.2. Flexible daily schedules

Except for agents with some temporary flexible contracts such as casual agents (see 2.2.3) who usually have very flexible daily work schedules, full-time and part-time agents, even shift or non-shift, have quite strict work schedules. Allowing these agents to have a flexible lunch break during a day (for example between 11 AM and 4 PM), flexible break time between two consecutive work shifts (for example, between 36 and 48 hours for any two sets of 12 work hours) or a flexible number of days off during the week (for example, between 2 and 4 days off for any two sets of 5 consecutive workdays) can increase the flexibility of the company workforce (Stolletz 2010). However, we need to be careful when increasing agents' flexibility because agents with regular schedules can know their workdays and periods a long time in advance, which satisfies them more. Therefore, regular daily schedules are more common in the context of stable demand while flexible daily schedules are found more often in the context of variable demand.

2.3.2.3. Multi-skilled agents

Agents with multiple skills can be assigned to different tasks requiring these skills. Therefore, having an important proportion of these multi-skilled agents can increase the chance that tasks are performed by suitable agents. To obtain a certain proportion of multi-skilled agents in the workforce, companies should not only register a unique skill and its level for an agent but also other skills if she/he has. Moreover, agents with multiple skills should be given priority in recruitment than those with only one skill. Then, the planning process should help to maintain agents' multiple skills by assigning them not only to the tasks requiring their unique skill but also sometimes to those requiring their other skills (Gruat-La-Forme, Botta-Genoulaz, and Campagne, 2006).

2.3.2.4. Extra agents

Extra permanent agents are often used to increase the global agents' work capacity or the rate between this capacity and the global workload required by tasks (Ferrand et al. 2011). The higher this rate is, the more likely all the tasks can be fulfilled. Moreover, having extra agents increases the chance for each task to find an appropriate agent and thus, increases the chance that all the tasks are performed by suitable agents. Besides, in unexpected cases like sickness or accident, extra agents can replace missing agents.

2.3.2.5. Extra hours

When the end times of too many tasks are outside daily agents' regular work times or when their total regular capacity is less than the total loads of tasks, allowing agents to have extra work hours can help increase the total agent capacity and the capacity at some critical times of the day. Moreover, in comparison to extra agents, presented previously, using agents' extra hours is more cost-effective for the company (Bard 2004). However, the numbers of extra hours per day and per week are regulated by labor law and have to be strictly met. Besides, too many extra hours can reduce the agent efficiency for the long term and their work satisfaction. A reasonable number of extra hours per week or month should be therefore obtained. The annualized work hours method, which uses a modulation counter to measure the accumulation of the differences between agents' real work time and their contract work time on many successive planning horizons (see Section 2.2.3), is often considered in the literature to regulate agents' extra work hours (Pastor and Olivella 2008).

Because demand variability requires workforce adaptation, when the variability is very small, using a workforce with a very high adaptation can significantly increase the costs associated. By contrast, when the demand variability is high, a workforce with a low adaptation may not be enough to cover the demand.

2.4. Conclusion

In this chapter, we propose three different approaches to characterize the work team building and planning problem. The first approach considers the four decision-making sub-problems and their combinations. Focusing on only one or two main sub-problems and using decomposition techniques for others can significantly reduce the problem complexity. For example, the team building can be considered as a result of the agent assignment when a team corresponds to a group of agents assigned to the same task. Moreover, agents can be assumed to use public transport to travel between homes and workplaces; the company, therefore, does not have to use their vehicles to pick the agents up at their homes and transport them to their workplaces. The second approach characterizes the problem by the five classes of objects, including the agents, clients, tasks, travel routes, and vehicles. This approach helps to identify and structure the data that will be used later for problem modeling. Moreover, depending on the situation of each company, only some realistic characteristics of several of these classes of objects are considered. Besides, the number of performance indicators associated with the classes of objects significantly affects the complexity of multi-objective optimization. As the number of objectives grows beyond three, Pareto dominance, a classic method for multi-objective problems, becomes ineffective (Curry and Dagli, 2014). The third approach studies the problem through demand variability and workforce adaptation. The more variable the demand is, the more flexible the workforce has to become and the more complex the modeling of the demand and workforce might be.

Based on these three characterization approaches, we can see that the work team building and planning is a problem quite complex that has a huge number of variants with different levels of complexity. Each variant corresponds to a combination of several decision-making problems, several characteristics of the five classes of objects associated with the problem, several performance indicators, and finally a demand with a certain variability and an adaptable workforce. We choose to investigate deeply two of these variants that are inspired by the real problem of our Brazilian partner company who provides services to businesses. The first case study corresponds to its current situation – important clients with stable, long-term, and repetitive demand. The second case study is an extension of the first case where the demands are assumed variable.

In chapter III, we conduct a literature review, based on the three characterization approaches proposed in this chapter. The objective is to identify the areas where the needs for solving this problem are located and thus where our thesis contribution should concentrate.

Chapter III. Literature review

Résumé en français

Dans ce chapitre, nous présentons une revue de la littérature sur le problème de la constitution et de la planification d'équipes de travail sur la base de 119 articles. Ces articles étudient des problèmes dans le domaine de la recherche opérationnelle pour la production, le service ou le transport. La revue comprend deux parties, l'une générale et l'autre plus approfondie.

La revue générale nous aide à préciser les caractéristiques de notre problème. Premièrement, les secteurs des soins à domicile et de la maintenance, dont notre problème est inspiré, sont les domaines d'application les plus courants de la littérature. Ensuite, les combinaisons d'au moins deux problèmes de prise de décision, comprenant l'affectation d'agents et la constitution d'équipes, qui sont intéressants pour notre étude sur le problème généralisé, sont fréquemment considérées. Puis, les demandes variables sont généralement considérées dans le domaine des services aux particuliers et les demandes stables se rencontrent plus souvent dans le domaine des services aux entreprises. Après, concernant la dépendance entre des horizons de planification, l'hypothèse simplificatrice selon laquelle toutes les ressources - agents - sont disponibles dès le début de l'horizon est souvent considérée, en particulier pour la recherche académique. En fin, la programmation mathématique, particulièrement la programmation linéaire à variables mixtes, est souvent utilisée pour modéliser le problème.

Pour la revue approfondie de la littérature, nous faisons un zoom sur deux parties des articles qui considèrent le problème dans le même contexte que chacune de nos deux études de cas et examinons leurs caractéristiques de manière précise et exhaustive. Pour la première partie concernant le problème dans le contexte de demande stable, nous constatons que l'approche de planification cyclique, avec laquelle le planning pour un horizon long est créé en générant un planning pour une durée courte (une semaine), et le répétant autant de semaines que les clients sont actifs, est souvent considéré. Deuxièmement, l'utilisation d'un nombre fixe d'agents permanents (sans agents sous-traités) est courante. Puis, les agents à temps partiel sont parfois considérés mais ceux avec des contrats flexibles ou temporaires ne sont pas considérés. Pour la deuxième partie concernant le contexte de demande variable, la planification acyclique est considérée au lieu de la planification cyclique. Des leviers organisationnels, incluant l'utilisation des contrats à temps partiel, de la polyvalence des agents, des heures de travail supplémentaires, d'un excédent de capacité de main-d'œuvre par rapport à la charge de travail, et de jours de congés flexibles, sont souvent considérés pour augmenter l'adaptation de la main-d'œuvre. En cas de demandes très variables, l'utilisation d'agents temporaires avec les dates de début et de fin flexibles et l'augmentation de la flexibilité des agents permanents sont souvent envisagées.

In this chapter, we conduct a literature review for the work team building and planning problem, which is based on the three characterization approaches presented in chapter II. The first objective is to clarify the general characteristics of our problem. Then, we have a particular focus on some specific articles, which consider the problem in the same contexts as our two case studies, including stable and variable demand. The objective is to investigate if some important characteristics that we are interested in are missing in the literature and then to search for the most appropriate approaches to model and solve each of these two variants.

The organization of the chapter is as follows: We start with the methodology to search for the articles (Section 3.1). Next, we conduct a general review to study some important macro characteristics of the problem (Section 3.2). Then, we focus on two parts of the articles that study the problem in the same contexts as each of our two case studies and investigate their characteristics comprehensively (Section 3.3). Finally, we give some conclusions for the chapter (Section 3.4).

3.1. Methodology

The literature review concerns a total of 119 journal articles and conference communications. We search for these articles on different websites/search engines. These include Google Scholar, ScienceDirect, Springer, and ResearchGate.

We use two groups of keywords to search for the articles. The first group corresponds to the common names of the variants of the problem studied, which include “scheduling”, “schedule”, “routing”, “planning”, “assignment”, “staffing”, “allocation”, “allocating”, “rostering”, and “timetabling”. The second group corresponds to the common names of the company’s workforce, which include “personnel”, “workforce”, “agent”, “employee”, “labor”, “technician”, “nurse”, “home care”, “home health care”, “therapist”, “physician”, “worker”, “manpower”, “team”, “crew”, “staff”, and “group”.

We first search for articles that contain at least one keyword of the first group and one of the second group. This searching strategy gives us 87 articles. Then, we search in their references for the articles that contain at least one keyword of the first group or the second group and are relevant to our study, the operations research for production, service, and transport. This gives us 32 additional articles.

Among 119 articles considered, 16 are communications in international conferences, 103 are journal articles that come from 40 different journals. The list of these journals is presented in the Appendix - Table A.1. The four journals with the largest numbers of articles considered are the European Journal of Operational Research, Journal of Scheduling, Transportation Research, and Computers & Operations Research with 20, 7, 7, and 7 articles respectively. This result shows that the articles chosen fit very well our research scope, which is the operational research for workforce planning or scheduling.

For the work team building and planning problem, most of the countries, from which the problems are original (if mentioned) or the first authors come, are developed countries, especially in Europe, followed by North America (including U.S. and Canada) and Asia with 59, 24 and 10 articles respectively. In Europe, the UK and France are the two countries that own the highest number of articles, with 11 and 10 articles respectively. This problem is less considered in developing countries[18] and most of these studies concern a problem in Asia or South America with 19 and 6 articles respectively. Among the six articles that studied this problem in South America, five of them consider a problem in Brazil from which our case studies are original. These results show that considering this problem is interesting for both the developed countries, such as France and developing countries, such as Brazil.

We divide the literature review into two parts. The first part (Section 3.2) considers some macro characteristics of the generalized problem such as the application sectors, the client types (business/individual), the decision-making problems considered, and the demand variability. In the second part (Section 3.3), we focus on a limited number of articles that are highly relevant to each of our two case studies and investigate their specific characteristics comprehensively.

3.2. General review

Regarding the application sectors, service, transportation, and production are the three most common sectors where the problem is studied. The numbers of articles studying an application in

[18] https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm

these sectors are 89, 10, and 5 respectively (Table 3). For all the lists of articles by sector, please see Appendix - Table A. 2. For the service sector in which the problem is the most frequently studied, the home health care, hospital care, and maintenance services are the three most relevant sub-sectors with 25, 18, and 18 articles respectively. These findings show the strong relationship between the application sectors of the articles considered and the scope of our study that is not the scheduling problem for production/manufacturing like job shop scheduling or lot-sizing, neither the routing problem for the distribution of goods. Our research scope is the workforce planning/ scheduling problem in the service domain. However, to keep the diversity of the application sectors, we also accepted the articles in other sectors different from the service. Moreover, the home health care and maintenance services are also the two sub-sectors of the two companies from which the real characteristics of our problem are inspired. This means that the articles considered here are highly relevant to our study.

Table 3. Number of articles by sector and sub-sector

Sectors	**Number of articles**	**Sectors**	**Number of articles**
General	**15**	**Service**	**89**
Production	**5**	Accounting service	1
Assembly lines	1	Airfreight handling	1
Factory	1	Ambulance service	1
General	2	Baggage claim at airports	1
Job shop	1	Call center	3
Transportation	**10**	Check-in at airports	2
Airline catering	1	Consulting	1
Autonomous robots	1	Education	1
Distribution	2	General	9
General	3	Home care	25
Postal service	2	Home care for offices	3
Waste collection	1	Hospital care	18
		Maintenance service	18
		Port worker	1
		Postal processing service	1
		Retail outlets	2
		Training service	1

As mentioned in Section 2.1, the work team building and planning problem can be regarded as the combination of four decision-making problems in operational research: agent assignment

(AA), team building (TB), activity planning (AP), and vehicle routing (VR) problems. However, these four sub-problems are not always considered explicitly, one or several of them are often simplified by using the decomposition techniques. The authors have, therefore, to deal with only one or several main decision-making problems. The agent assignment problem is the core decision-making problem of our problem and is studied in all the 119 articles considered (Table 4). The most common combinations are those between the agent assignment (AA), the activity planning (AP), and the vehicle routing (VR) problems or between the agent assignment (AA) and the team building (TB) problem with 42/119 and 40/119 articles respectively. The number of articles considering all four sub-problems is small but not ignorable (10/119). Studying this generalized case considering all the four sub-problems is a potential direction to follow. Moreover, the combinations of the two problems (AA+TB) and the three problems (AA+TB+AP), which are interesting for our two case studies, are often considered in the literature (49/119).

Table 4. Number of articles by the combination of decision-making problems

Combinations of decision-making problems	**Number of articles**
AA	1
AA + TB	40
AA + AP	7
AA + VR	3
AP + VR	7
AA + TB + AP	9
AA + AP + VR	42
AA + TB + AP + VR	10
Total	**119**

AA: agent assignment, TB: team building, AP: activity planning, VR: vehicle routing

Of the four decision-making problems, team building is not a name commonly found in the literature even though in our review it is considered in 59 articles. This is because the team-building problem is more often considered implicitly than explicitly. We found three main reasons why this problem is taken into account. First, the company/institution needs a certain number of agents working together in the same period to ensure its normal work capacity (39/59). Then, a team is formed by the agents who perform the same task. In this case, a team corresponds to a task (16/59). Finally, when agents of a team have to stay together for a certain long duration (day or week) and use the same vehicle to travel to different workplaces to perform tasks (4/59). The team can perform several different tasks during a day in this case.

The vehicle routing problem is frequently taken into account when considering all the application sectors (62/119) or only the service sector (47/89). In the service sector, this problem always goes together with on-site service delivery. Besides, among 83 articles concerning the service sector (excluding 6 articles in the general service sub-sectors), the services required by individual clients (27/83) are always on-site services, which means that they have to be provided at the clients' homes such as home health care or ambulance transfer services. These findings mean that the three macro-characteristics, including the service-to-individual sector, the on-site service delivery, and the consideration of the vehicle routing problem have a strong relationship. Therefore, when we consider the problem in the service-to-individual domain, we also consider the on-site service delivery and the vehicle routing problem.

Concerning the demand variability, we found four situations corresponding to four different types of demand variability. First, when the total demands are not different between days, weeks, or months (also called stable demand). This situation is found in some service-to-business sectors such as hospital care (Kundu et al. 2008), waste collection (Bruecker et al. 2018), or postal delivery service for businesses (Laporte et al. 1987). Second, when the article does not consider the demand variability explicitly where only one or several real instances with the same demand size are tested in the experiments (Lesaint, Voudouris, and Azarmi 2000; Xu and Chiu 2001). Then, when the demand is different between planning horizons and it is deterministic. Most of the articles considered in this literature review belong to this category (82/119). The causes of variability can relate to the ratio of demands' workload and agents' capacity (Bard et al. 2014; Bertels and Fahle 2006; Shao, Bard, and Jarrah 2012), proportions of demands with different levels of complexity such as precedence and synchronization constraints (Mankowska et al. 2014), time-windows widths (Taş et al. 2014). The last situation, the stochastic demand, corresponds to the highest demand variability. The most frequently considered stochastic elements are the number of demands, the demand duration (Borenstein et al. 2010; Lei, Laporte, and Guo 2011; Yuan, Liu, and Jiang 2015), the arrival time of a demand (Rashidnejad, Ebrahimnejad, and Safari 2018; Su et al. 2019). In Section 2.3.1, we identified two demand types by its variability, including stable and variable demands. In the literature, the number of articles considering a stable demand is quite small (15/119). Most of them consider variable demand (93/119). Among these 93 articles, 82 studies a problem with deterministic variable demand while only 11 consider a stochastic variable demand.

There is a relation between the client types, the service sector, and the demand variability. In some service sectors like hospital care, the subcontracting company provides agents to one or several hospitals in an area. Because the demand of each client (hospital) is large and stable over time, the total company's demand is, therefore, also stable and usually expressed as a demand per day with a repetitiveness over the week. In some other business sectors like check-in, freight handling at the airports, maintenance services for businesses, a large number of small businesses is usually considered, the demand of each client can be repeated but with a very low frequency, usually maximum one time per week. Each client demand can be generally stable but the total demand of all the clients is usually variable. Regarding the services to individuals, in some sectors like home health care, the company usually has a large number of individual clients and each of them has a daily demand with a repetitiveness over the week. The total demand is, therefore, variable and depends on the stability of the demand size of each client and the number of new clients per horizon. For some other sectors, such as call centers, ambulance service, and consulting service, we do not have a stable number of clients; the clients of each day, each period of day are generally new clients. Most of the demands are, therefore, one-time demands. This type of demand is more variable than the previous types.

Short planning horizons of one or several days are more often considered than long planning horizons of at least several weeks (see Table 5). Moreover, we found that the more variable the demand is, the shorter the planning horizon is considered. For the 11 stochastic demands, 10 of them consider a planning horizon of one or several days. For the 15 articles related to stable demand, all of them consider planning horizons of at least several weeks. Briefly, depending on demand variability, a short or long planning horizon should be considered.

Table 5. Number of articles by the planning horizon

Planning horizon	**Number of articles**
1 day	34
several days or 1 week	53
several weeks or 1 month	19
At least several months	13
Total	**119**

Regarding the dependence between agents' activities on two consecutive planning horizons, the articles can be divided into three categories (see Table 6). The first one, the "fully" independent case, which occupies most of the articles studied (110/119). With this consideration, authors assume that all the resources – agents – are available from the beginning of planning horizons and the work plan in each planning horizon is, therefore, independent from the others. The second category is named independent with annualized work hours. "The annualized hour scenario implies that the number of work hours in a year can be irregularly spread over the weeks, but the annual number of work hours is fixed. Employees earn the same wage each month" (Azmat al. 2004). This method allows better distributing agent capacity through the year, which means more capacity for the horizons with high demand and less capacity for those with low demand. The next category is independent with repetitive planning, in which agents' work plan for the current horizon is mainly based on that of the previous horizon but some minor modifications may be added. This consideration makes sense only when the demands are repeated after each planning horizon and few unexpected events happen (Burke et al. 2007; Eveborn et al. 2006). In conclusion, for academic research, the "fully" independent case is commonly used even if it may not be quite realistic. The independent with annualized work hours seems to be a good way to increase workforce flexibility.

Table 6. Number of articles by the dependence between planning horizons

Type of dependence	**Number of articles**
"Fully" independent	110
Independent with annualized work hours	5
Independent with repetitive planning	4
Total	**119**

Of the modeling and solving methods considered, the meta-heuristic and mathematical programming methods are the two most common methods for our problem with 60 and 46 articles respectively. Of the mathematical programming techniques, the (mixed) integer linear programming is often used (33/46). Regarding the meta-heuristic methods, local/neighborhood search (19/60), Tabu search (11/60), simulated annealing (8/60), and genetic algorithm (8/60) are usually considered. The list of all the resolution methods and their corresponding number of articles are presented in Table A.3.

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3.3. In-depth review

The general review in the previous section allows us to investigate the macro characteristics of our generalized problem. For in-depth studies, we focus on two parts of the articles that study the problem in the two contexts (stable and variable demand), corresponding to our two case studies. These case studies are inspired by the real situation of the Brazilian company. The first case study (Chapter IV), corresponding to the context of stable demand, in which each demand generally requires a large number of agents working together in a team and the team-client assignment is usually fixed for a long duration. However, the clients are increasingly requesting services with variable demands between days and weeks. The current workforce organization, which is built to cover stable demand, is not flexible enough to cover these new types of requests. This situation will be the subject of our second case study (see Chapter V).

3.3.1. Context of stable demand

The in-depth review for the first case study concerns 12 articles (see Table 7). The problem in the service-to-business domain and context of stable demand is usually called the days-off and shift scheduling or the tour scheduling problem, in which the company determines the workdays and days off on the planning horizon and the work and break periods of workdays for their agents. The planning horizon considered is long, usually, 3 months, 6 months or 1 year, and the planning horizon is several days or several weeks (see Table 7). The work plan for a long planning horizon is often obtained by creating a work plan for a short duration and then repeating it many times. This type of schedule is called cyclic scheduling. Most of the articles considered in the literature use cyclic scheduling. The advantages and disadvantages of this way of scheduling are presented in (Bester et al. 2007): "…cyclical scheduling is effective because coverage is balanced across the days and shifts of the schedule, because employees know their work schedules well in advance and because schedules are only generated when there are changes in scheduling requirements, but fails to deal with varying workload, unexpected absentees and changing personnel preferences".

Table 7. In-depth review for the context of stable demand

Article	Planning horizon	Planning cycle	Cyclic/ acyclic planning	Days-off/ shift planning	Shift pattern	Cyclic agents' shifts/ days off	Flexible contracts	Workforce size	Criteria				Skills
									TC	ASC	WB	AP	
Alfares 1998	long	several weeks	cyclic	days-off planning	8h	Days off		infinite		X			
Beaulieu et al. 2000	6 months	several days	acyclic	both	8h-8h-8h		part-time	fixed			X	X	
Carrasco 2010	1 semester	several weeks	cyclic	both	12h-12h			large enough			X	X	X
Carter and Lapierre 2001	3 months	several weeks	both	both	8h-8h-8h		part-time	fixed			X	X	
Ferrand et al. 2011	1 year	8 weeks	cyclic	both	8h-8h-8h			fixed			X	X	
Kundu et al. 2008	long	2 weeks	cyclic	both	7h-7h-11h			infinite		X		X	
Laporte and Pesant 2004	long	several weeks	cyclic	both	8h-8h-8h			fixed			X	X	
Millar and Kiragu 1998	long	several weeks/ days	both	both	12h-12h		part-time	fixed		X			
Rocha et al. 2013	1 year	several days	cyclic	both	6h-6h-6h-6h		part-time	infinite part-time		X	X	X	
Rosenbloom and Goertzen 1987	long	2 weeks	cyclic	both	-			fixed		X			
Salem and Sherali 2007	long	several weeks	cyclic	both	8h-8h-8h			fixed		X	X	X	X
Sundari and Mardiyati 2017	1 year	21 days	cyclic	both	7h-7h-10h			large enough			X	X	
Our study	6 months	1 week	cyclic	both	12h-12h; 12h; 8h	both		fixed	X		X	X	X

TC: travel costs, ASC: assignment costs, WB: workload balance, AP: agents' preferences

Most of the 12 articles considered are in the hospital care sectors, including nurses, therapists, physicians, and operation rooms scheduling. Clients' demand in these sectors is generally quite stable over the long term (column 2, Table 7). We found two common types of demand corresponding to two different numbers of required days per week and required hours per day. In the first one, the service is required 24 hours per day and 7 days per week (Kundu et al. 2008; Laporte and Pesant 2004; Rocha, Oliveira, and Carravilla 2013). The second requires 8 or 12 service hours per day (usually between the morning and the evening) and for between 5 and 7 days per week (Alfares 1998). The work plan for the second type of demand can be obtained by using only the days-off scheduling method (Alfares 1998) because each agent usually has a fixed work shift of 8h or 12h every day. However, using days-off scheduling is not enough for the first type of demand. This is because working the same period (morning, evening, or night) every day increases agents' dissatisfaction, especially those who work during the night. Moreover, this way of scheduling does not ensure agents' preferences for different work periods on different days. Therefore, both days off and shift scheduling are often considered together for the first type of demand. A 24h workday can be divided into 3 shifts, non-overlap like 8h-8h-8h and 7h-7h-10h or overlap like 7h-7h-11h, or into 2 shifts 12h-12h or 4 shifts 6h-6h-6h-6h (see column 6, Table 7).

To cover these types of stable demand, a fixed number of full-time agents are usually considered. This number is obtained at the tactical or strategical level when the company uses its historic demands to forecast future demands. However, the estimation of this fixed number of necessary agents should be considered carefully to ensure the balance between the workforce capacity and the workload required. The number of available agents (or workforce capacity) is sometimes assumed to be infinite (Alfares 1998; Sundari and Mardiyati 2017) or very large in comparison to the workload (Carrasco 2010) and the objective is to determine the minimal workforce size so that all the tasks can be fulfilled. Full-time agents are always considered. Part-time agents are sometimes considered as a complement for the full-time. Using part-time agents increases the workforce flexibility but we should also take into account their higher salary costs in comparison to those of the full-time agents (Millar and Kiragu 1998; Rocha, Oliveira, and Carravilla 2013). By contrast, temporary contracts are not considered in the 12 articles surveyed. The overtime is neither studied because the smallest work unit is a work shift and each agent can generally work a maximum of one shift per day. Concerning agents' flexibility, most of the articles consider agent contracts with flexible shifts and days-off patterns; only one article considers a cyclic agent days-off pattern with 5 consecutive workdays and 2 consecutive days off per week (Alfares 1998).

Unscheduled tasks are generally not allowed in this type of problem. We found one case where the problem is very constrained and unscheduled tasks are allowed. In order to evaluate the performance of different solving methods, the number of violated constraints was measured (Millar and Kiragu 1998). Another article (Carter and Lapierre 2001) considers a two-step solving method. First, they try to solve the problem with all the constraints. If a feasible solution cannot be found, only hard constraints are kept and soft constraints are converted into objectives, which means that they try to minimize the penalty costs related to the violation of these soft constraints.

Concerning the objectives, all the articles consider that the service is provided at the company/institution offices and the routing problem is not considered. Moreover, most of the articles aim at maximizing the workload balance between agents and their preference satisfaction, especially for days off of the week (Carter and Lapierre 2001; Kundu et al. 2008) and sequence of shifts and breaks (Laporte and Pesant 2004; Rocha, Oliveira, and Carravilla 2013). Some consider the agent assignment costs like the over-coverage costs associated with agents' idle time (Ferrand et al. 2011), the total workforce costs (Kundu et al. 2008), or part-time costs (Rocha, Oliveira, and Carravilla 2013).

Labor regulations and time windows are always considered as constraints. The labor regulation concerns the minimum and maximum work time per day and per week, the lunchtime, the minimum break time for a certain duration of work time, the maximum number of consecutive workdays, etc. The time-windows constraints refer to the fact that each shift has start and end times and all the agents assigned to the shift have to be present during this duration. Regarding agents' skills, most of the articles consider homogeneous agents. Only two articles consider the agent-task skill compatibility constraints (Carrasco 2010; Al-Yakoob and Sherali 2007).

3.3.2. Context of variable demand

The in-depth review for the problem in the context of variable demand concerns 18 articles. The important characteristics of these articles are presented in Table 8.

Table 8. In-depth review for the context of variable demand

Article	Planning horizon	Weekly service days	Daily service time	Demand variability	Workforce adaptation levers							Criteria				
					Contract types	Over-time	Annu-alized hours	Extra agents	Shift flex.	Days off flex.	Multi-skilled agents	TC	ASC	WB	AP	CP
Avramidis et al. 2010	1D	N/A	9/24	high	FT, PT				X		X		X			X
Bard 2004	1W	7/7	24/24	high	FT, PT, TP, FL	X	X	X	X	X			X		X	
Bester et al. 2007	3M	7/7	24/24	low	FT	X		X		X	X			X	X	
Burke et al. 2007	1M	7/7	24/24	low	FT	X			X	N/A	X		X	X	X	
Chu 2007	1W	7/7	24/24	high	FT	X		X	X	X			X			
Constantino et al. 2011	1W	7/7	24/24	low	FT	X		X		X			X	X	X	
Dias et al. 2003	1W	7/7	24/24	N/A	FT	X				X			X			
Goodman et al. 2009	Ds	7/7	17/24	N/A	FT, PT					X	X				X	
Hertz et al. 2010	1W	7/7	24/24	high	FT, PT	X	X	X		X			X	X		
Parisio and Jones 2015	1W	5-7/7	14/24	high	FT, PT	X			X	X	X		X		X	
Parr and Thompson 2007	Ws	7/7	8 or 24/24	N/A	FT, PT						X		X		X	
Pastor and Olivella 2008	1W	6/7	15/24	high	FT, PT	X	X		X	X			X		X	
Rong and Grunow 2009	1W	7/7	24/24	high	FT, PT			X	X	N/A	X		X			
Rönnberg and Larsson 2010	Ws	7/7	24/24	low	FT, PT	X	X	X		X	X		X	X		
Stolletz and Zamorano 2014	30D	7/7	24/24	low	FT, PT, TP, FL	X	N/A	X	X	X	X		X			
Stolletz 2010	2W	7/7	17/24	high	TP, FL			X	X	X					X	
Topaloglu and Ozkarahan 2004	1W	7/7	8,16, 24/24	low	FT, PT	X			X	X			X		X	
Topaloglu 2006	1M	7/7	24/24	low	FT					X	X			X	X	
Our study	1W	7/7	24/24	low, high	FT, PT	X	X	X	X	X	X	X		X	X	

D: day, Ds: several days, W: week, Ws: several weeks, M: month, FT: full-time, PT: part-time, TP: temporary, FL: flexible, flex.: flexibility, TC: travel costs, ASC: assignment costs, WB: workload balance, AP: agents' preferences, CP: clients' preferences, N/A: not mentioned

In the context of stable demand, cyclic scheduling is commonly used (see Section 3.3.1). However, in the context of variable demand, cyclic scheduling is not often used because of the low flexibility of the work plan created (Bester, Nieuwoudt, and Van Vuuren 2007); acyclic scheduling is preferred. The weekly service days and daily service hours are usually 7 days / 7 and 24h / 24, sometimes 8-9h /24 corresponding to the day shift or 15-17h / 24 corresponding to the day and evening shifts (column 3-4, Table 8).

The demand variability can be low or high. Low variability means that the demand is not too different between planning horizons while a high variability usually associates with stochastic elements such as the number of required tasks and their start times (column 5, Table 8).

To cover variable demand, different levers are often considered to increase workforce adaptation. The first consideration concerns flexible contracts (column 6, Table 8). Besides regular contracts that are commonly studied in the articles, we found two cases where flexible permanent and temporary contracts were also considered to deal with the demand variability (Stolletz and Zamorano 2014; Bard 2004). One article considers only agents with flexible temporary contracts (without permanent contracts) to reduce workforce costs (Stolletz 2010). Having agents work extra hours is generally considered in most of the articles (column 7, Table 8). Two common ways to consider these extra hours are traditional overtime (Chu 2007; Constantino et al. 2011; Dias et al. 2003) and overtime under annualized work hours (Hertz, Lahrichi, and Widmer 2010; Hung 1999; Pastor and Olivella 2008). With traditional overtime, each agent is assumed to be able to work a maximum number of extra hours every day, week, and month. This approach is simple and easy to manage but it does not give enough workforce flexibility in cases where the demand fluctuates widely between planning horizons. The second approach is more appropriate in these situations (column 8, Table 8) "the use of annualized working hours allows a company to adjust the weekly available time to reduce idle capacity or to fulfill requirements that could mean overtime" (Hertz, Lahrichi, and Widmer 2010). To manage the difference between the real work time and the contract work time to calculate the annualized work hours, a modulation counter is often used. This modulation counter usually cannot exceed a certain number of hours (Pastor and Olivella 2008). Then, most of the articles consider a fixed number of available agents while some assume that the number of agents is infinite and they try to minimize the workforce size (column 9, Table 8). When extra agents are considered, they are usually not the company's permanent agents but outsourced with a short-term contract (Parr and Thompson 2007; Rönnberg and Larsson 2010; Bester, Nieuwoudt, and Van Vuuren 2007).

Shift flexibility, including flexible start and end times, variable shift length is often considered, especially when the demand variability is high (column 10, Table 8). (Bard 2004; Dias et al. 2003; Parr and Thompson 2007) consider both shift start and end times and shift length flexibilities when a part-time agent can have five different shift lengths (4h, 5h, 6.5h, 7.5h, and 8.5h) and 24 possible shift start and end times. Days-off flexibility is usually considered (column 11, Table 8). Some articles set a minimum and a maximum number of days off per week, which can be consecutive or not (Stolletz and Zamorano 2014). Some fix one day off to be Sunday and let the other days off flexible (Pastor and Olivella 2008). Some allow agents to choose their days off preferences and try to maximize these preferences (Rönnberg and Larsson 2010).

Multi-skilled agents are often studied when an agent can have, in addition to his/her main skill, some other secondary skills (column 12, Table 8). (Stolletz and Zamorano 2014) study the problem for multi-skilled check-in agents – also called “generalists” by the authors – at airports. They consider the impact of the skill distribution on the overall scheduling costs. They conclude that “additional flexibility can be gained by increasing the proportion of generalist agents in the workforce”. However, we should be careful when considering these multi-skilled (“generalist”) agents: “the full benefits of adding additional fully qualified agents have less impact when 20% or more generalists are present in the workforce” and “this additional flexibility can be acquired at a higher cost if salaries depend on the number of qualifications of the agents”.

Regarding objectives (see columns 13-17, Table 8), the travel costs are not considered. Assignment costs are usually studied and concern the minimization of the total number of agents, the amount of overtime, or waiting time. Workload balance and agents’ preference satisfaction are also often taken into account while clients’ preferences are not often considered.

3.4. Conclusion

In this chapter, we used 119 articles, studying different problems in the fields of production, service, and transport and at the operational level, to conduct a literature review for the work team building and planning problem. Two parts of the review were considered, including the general and the in-depth reviews.

The general review helped us specify the characteristics of our problem. First, the service sector, home health care, and maintenance service sectors, from which our problem is inspired, are the most common application areas in the literature. Second, the combinations of at least two decision-making problems, including the agent assignment and the team building, which are particularly interesting for our study, are frequently considered. Next, variable demand is usually considered in the service-to-individual domain while stable demands are usually found in the service-to-business domain. Moreover, clients with stable demand often conclude their contracts over several months, which allows cyclic weekly planning. Then, regarding the dependence between planning horizons, the simplifying assumption that all the resources – agents – are available from the beginning of the planning horizon is commonly considered, especially for academic research. Finally, mathematical programming techniques, especially the mixed-integer linear programming, are commonly used to model the problem. Moreover, this modeling method is often combined with the Cplex solver to solve problems with small-to-medium size.

For the in-depth review, we focused on two parts of the articles that consider the problem in the same context as each of our two case studies and investigated their characteristics comprehensively. For case study 1, corresponding to the context of stable demand, we found that first, the cyclic planning approach, in which the work plan for a long planning horizon is created by generating a work plan for a short duration (week) and repeating it as many times as clients are still active, is usually considered. Then, using part-time contracts is common while temporary contracts or those with very flexible work schedules are not considered. The last row of Table 7 on page 48 synthesizes the characteristics considered in case study 1. For case study 2, corresponding to a context of variable demand, acyclic scheduling is considered instead of cyclic scheduling. Then, some following organizational levers are often used to increase workforce adaptation: flexible part-time contracts, multi-skilled agents, annualized work hours, extra agents, and flexible break. Finally, when demand varies widely, using flexible temporary agents and allowing regular agents to have shift length, start and end times flexibility are often considered. The last row of Table 8 on page 51 synthesizes the characteristics considered in case study 2.

The two next chapters are dedicated to two case studies.

Chapter IV. Work team building and planning problem in the service-to-business domain and context of stable demand

Résumé en français

Dans ce chapitre, nous étudions le problème de constitution et de planification d'équipes de travail dans le domaine du service aux entreprises et le contexte de demande stable. Ce problème correspond à la situation actuelle de notre partenaire brésilien. Dans notre étude, pour simplifier le processus d'affectation, nous avons modélisé la demande avec des types de couverture de tâche de manière à ce que chaque type de couverture de tâche correspond à un type de contrat de travail. Les types de couverture de tâche caractérise la durée qui correspond à la fenêtre temporelle des tâches ainsi que leur répétitivité quotidienne sur la semaine.

L'entreprise crée un planning « local » pour chaque ensemble de nouveaux clients et agents toutes les 3 semaines. Le planning global pour tous les clients et agents est une agrégation de tous ces plannings « locaux » pour les contrats actifs. Cette manière de planifier permet de conserver l'affectation agent-client jusqu'à la fin de leur contrat, et donc d'assurer l'efficacité des agents au travail par la régularité d'affectation. Cependant, elle ne profite pas des avantages d'une ré-planification qui pourrait à la fois réduire les coûts pour l'entreprise et réduire les temps de trajets pour les agents. Nous avons proposé dans ce chapitre une approche de planification à deux niveaux qui inclut une planification « locale » multi objectif et une planification « globale ». La planification locale est une planification cyclique sur un horizon d'une semaine utilisée pour créer, sur un terme court (T1 semaines), des plannings initiaux pour chaque petit groupe de nouveaux clients et agents. La planification globale, toujours planification cyclique, créée pour un terme plus grand (T2 semaines > T1), fournit des plannings révisés pour tous les clients et agents actifs, dans la mesure où l'affectation initiale a duré au moins un certain temps (T3 semaines). Cette dernière durée peut être égale à la fréquence de la re-planification globale.

Deux modèles de programmation linéaire mixte ont été développés qui nous ont permis de réaliser des expérimentations numériques sur la base de données réelles fournies par notre partenaire brésilien. Les solutions optimales ont été obtenues en quelques secondes à la fois

pour les planifications locale et globale, ce qui montre l'efficacité de notre approche de modélisation et de résolution. Les résultats de l'expérimentation montrent la supériorité de notre planification à deux niveaux par rapport à la planification manuelle exclusivement "locale" de l'entreprise. Elle donne la solution optimale avec à la fois de meilleurs critères considérés, incluant les coûts de déplacement mensuels moyens par agent (TC) et la satisfaction des agents associée à leur durée moyenne de voyage (TT), de 7,1% et 10,9% respectivement par rapport à la planification de l'entreprise. En outre, notre approche de planification à deux niveaux surpasse l'approche de planification avec un seul niveau, qui est couramment considérée dans la littérature. Les pourcentages moyens d'amélioration pour TC et TT sont respectivement de 2% et 4%.

La décomposition selon le type de contrat d'agent a été utilisée dans ce chapitre pour simplifier le processus de planification, en particulier pour la planification manuelle que l'entreprise utilise. Cependant, l'efficacité de cette technique dépend de manière significative du nombre de contrats différents disponibles. Avec les quatre contrats actuels, l'entreprise ne peut pas satisfaire les nouveaux types de couverture de la demande qui sont de plus en plus demandés par ses clients. Ceux-ci incluent des « petites » demandes, par exemple seulement 4 heures par jour, plusieurs jours par semaine et des demandes variables avec différents nombres de jours par semaine, par exemple, 5 jours une semaine, 6 jours une autre semaine et 7 jours une troisième semaine. Ces situations font l'objet du Chapitre 5, dans le contexte de demande variable.

This chapter considers the work team building and planning problem in the context of stable demand, which corresponds to the current situation of our partner company. Currently, clients' demands are the same from week to week and on a long term. A work plan for such a demand is currently fixed until the end of the client contract. This way of planning is simple, can be created manually by the planner, and by keeping each agent at the same workplace for a long time, it ensures his/her work efficiency. However, it does not take advantage of the opportunities of a re-planning that can reduce the global costs for the company (transportation costs) and increase the satisfaction of its agents (work close to their home). We propose here a two-level planning approach, which creates work plans quickly for new clients and take advantage of the opportunities of re-planning. A preliminary version of this work gives the materials for a conference paper (Doan et al. 2019a).

4.1. Introduction

The work team building and planning problem in the service-to-business domain and context of stable demand is inspired by a real problem found in the Brazilian company. This subcontracting company signs contract with clients one month before the first day of service and it has, therefore, about 4 weeks to search for the agents to fulfill the contract and to define their work plans. The manual planning is currently used to create work plans for all the clients' contracts signed in the same time span and all the agents recruited for these contracts (see Figure 4). Because the time needed for recruiting agents for each contract is about 1 week, the planning should, therefore, be considered every 3 weeks. Figure 4 shows that all the clients whose contracts are signed between the first day of week 3 and the last day of week 5 are considered together in the manual planning in week 7. However, the first day of service of each individual client is independent of the others, for example, weeks 8 and 9 for clients 2 and 3 (client group 2) respectively.

To start planning, all the information concerning clients and agents has to be available at the beginning of the planning time. In the case that a new contract arrives late and the recruitment process cannot be finished before the start of the current planning, the contract should be considered in the next planning (client 1 of group 2, Figure 4). Moreover, because the first day of service is always the beginning of the week (Monday), even if a client contract is not signed on

Monday, the first day of service is always the first Monday after 4 weeks (for example, client 3 of group 1 or 2, Figure 4).

Figure 4. Recruitment, planning, and service providing for new clients' contracts

In the service-to-business domain, agents' work efficiency depends on their familiarity with the workplace. They always need time to get used to a new workplace before everything becomes settled. Therefore, keeping an agent at the same workplace for a sufficiently long duration is important to ensure his/her efficiency at work. However, keeping the assignment permanently does not take advantage of the opportunities of a re-assignment that could reduce costs and save time for the company. Moreover, when the assignment lasts for quite a long time, it increases agents' lassitude at work, which both makes them unhappy and reduces their work efficiency. Changing their assignments can solve this issue. Good planning, therefore, should give a solution with a compromise between the long-term use of the initial assignment for a maximum agent efficiency, and the re-assignment to take advantage of new opportunities in terms of cost reduction and travel time saving.

We propose here a two-level planning approach, including local planning and global planning or re-planning (see Figure 5). The thin lines represent the decisions from local planning, while the thick lines correspond to global planning (colors change each time new global planning is considered). The local planning, which is performed every short duration (T_1 weeks, for example, 3 weeks in the case of the Brazilian company), helps provide the initial work plans quickly for a set of new clients' contracts (clients 1-3, clients 4-5 or clients 6-8, Figure 5). The global planning, which is performed every long duration (T_2 weeks, for example, 24 weeks), provides new work plans for all the currently active clients and agents. To ensure a minimum work duration at each workplace that helps attain a certain level of work efficiency for agents, clients, and agents who have been assigned together for less than a certain minimum duration (T_3 weeks) will not be considered in the global planning. For the same T_1 and T_2, the larger T_3 is in comparison to T_2, the less frequent a client-agent assignment will be modified and thus the more stable the assignment is. However, when T_3 is smaller than T_2, the rate between T_3 and T_2 only affect the assignments of some new clients, not those who have been served by the company for at least T_2 weeks. To simplify the presentation of the two-level planning, we consider that T_3 equals T_2.

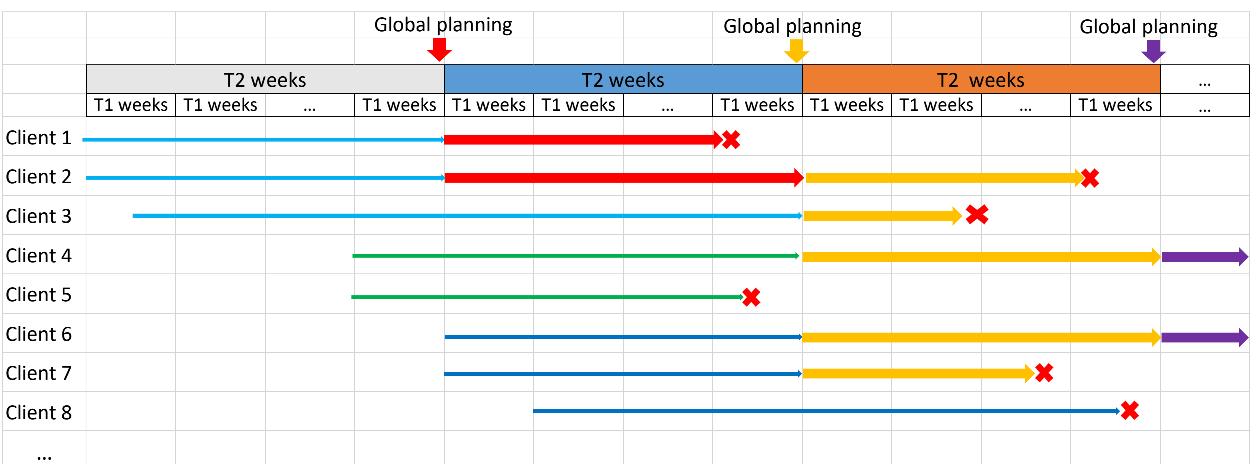

Figure 5. Our two-level planning approach

For local planning, which provides an assignment for a set of new clients, we aim at searching for a solution with a compromise between two criteria. These include the minimization of the average weekly travel costs per agent and the maximization of agents' satisfaction by minimizing the average trip duration between their homes and workplaces. With the global planning, the objective is to find a solution that minimizes the global average weekly travel costs per agent and ensures the non-degradation condition for the trip duration of each agent obtained by this global planning in comparison to the previous planning. The non-degradation condition ensures the satisfaction of the agents who do not want to spend more time traveling than what they were used to in the previous work plans.

In Section 4.2, we present some important problem characteristics. Next, we consider the two-level planning approach, including local planning and global planning in Sections 4.3 and 4.4 respectively. We propose a mathematical modeling and solving method for each planning level. Then, we present the results of numerical experiments with real data to assess the performance of the methods proposed. Finally, we give some conclusions and discussions about this two-level approach in Section 4.5.

4.2. Problem characterization

The problem is characterized through the four classes of objects, presented in the class diagram below (Figure 6) and consisting of clients, tasks, agents, and travel routes. This class diagram is a particular case of the class diagram of the generalized problem presented in Section 2.2. The common characteristics of these classes, which were already explained in Section 2.2, will not be reintroduced here. We only focus on some special characteristics of this case study.

4.2.1. Client

See Section 2.2.1

4.2.2. Task

A client does not directly express the tasks presented in the class diagram (Figure 6). The company generates them based on clients' demands. In order to understand the task characteristics, we look at the characteristics of clients' demands. About one month before the first day of service, the company signed a service contract with the client, which specifies the contract duration, workplace address, required service type, workplace type, demand coverage type, number of required agents, standard costs and extra costs, penalty and maximum number of unscheduled tasks allowed.

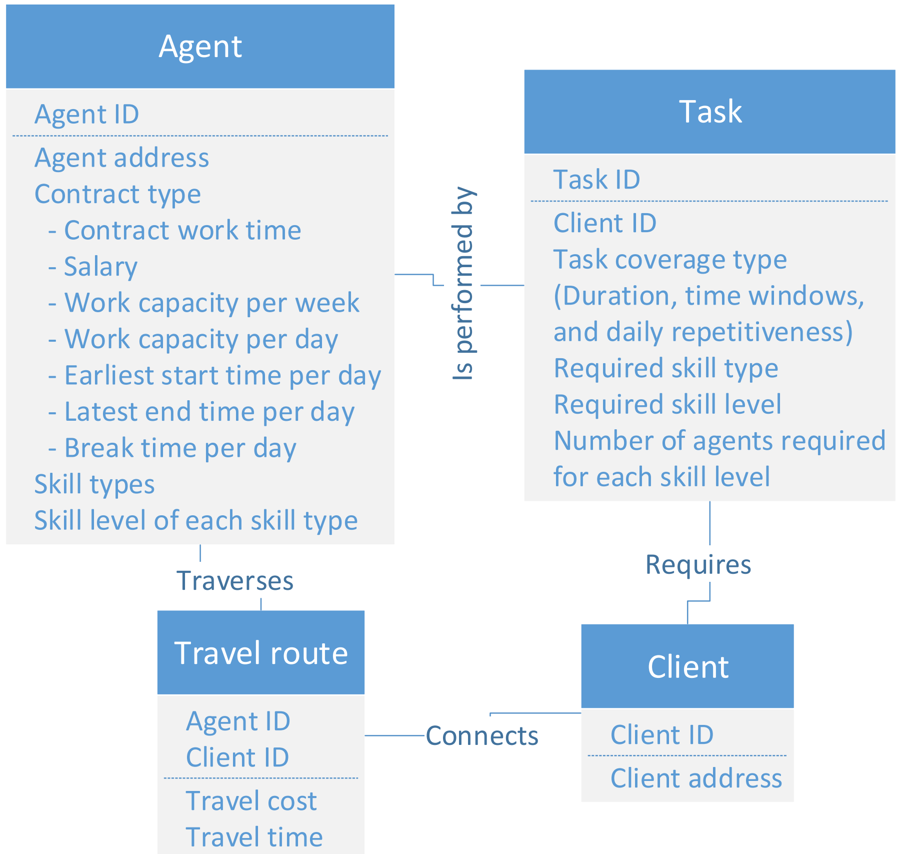

Figure 6. Class diagram for the problem in the context of stable demand

Contract duration: is normally one year with some fixed terms. Only some extra terms are added during the year if necessary, like adjusted prices. The contract is automatically renewed every year if the company does not receive any notification from its client. Otherwise, the client has to notify the company at least one month before the last day of the current contract.

Demand coverage type: is a combined characteristic of three common demand characteristics, including the demand duration and time windows per day, and its daily repetitiveness. The service company has a list of available demand coverage types, in which its clients can choose. This list is based on real clients' demands that the company provides and agents' work capacity imposed by labor regulations. The Brazilian company is currently providing four demand coverage types numbered from 1 to 4 (see Table 9).

Table 9. Brazilian company's current demand coverage types

Demand coverage type	Number of daily service hours	Daily start and end service times	Number of weekly service days	Weekly start service day
1	8h/24h	8am – 4pm	5/7	Monday
2	8h/24h	8am– 4pm	6/7	Monday
3	8h/24h	8am– 4pm	7/7	Monday
4	24h/24h	8am– 8am	7/7	Monday

Number of required agents: is the number of agents working in parallel at each moment to cover the demand.

Based on client demands, the company creates tasks to assign to their agents. Here is the description of the task characteristics presented in the class diagram (Figure 6):

Task coverage type: The two demand coverage types 1 and 2 (Table 9) can be assigned to a single group of agents who have the same start and end times per day and the same start and end days per week. We can, therefore, use the two task coverage types 1 and 2 (see Table 10) to characterize these two demand coverage types. However, we cannot use a single group of available work contracts to cover demand coverage types 3 or 4. No agents can work 7 days per week or 24h per day. The company is using six and four agent groups working in sequence to cover these demand coverage types respectively. A demand with coverage type 3 can be divided into 6 tasks of 6 different task coverage types (see Figure 7). Each has different start and end days during the week and can, therefore, be performed by a different group of agents. We use a new characteristic, which is the first service day of the first week, to represent each of these task coverage types (see task coverage types 3-8, Table 10).

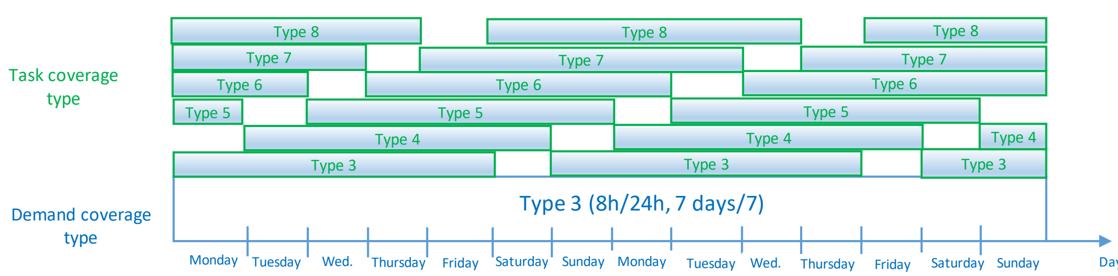

Figure 7. Task coverage types decomposed from demand coverage type 3

Similarly, a demand with coverage type 4 is divided into 4 tasks of 4 different task coverage types (see Figure 8). We use two new characteristics including the first service day of the first week and the daily start service time to represent each of these types (task coverage types 9-12, Table 10).

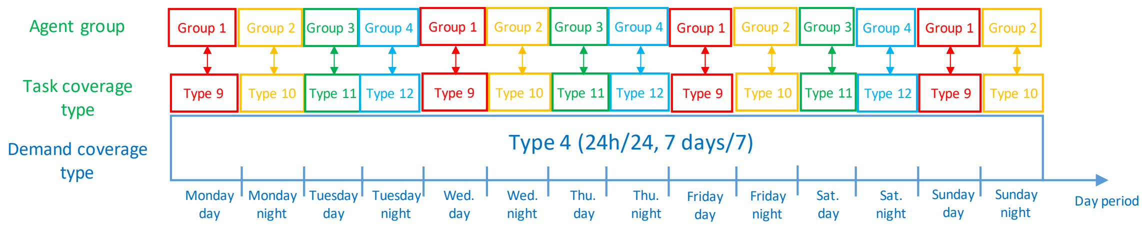

Figure 8. Task coverage types decomposed from demand coverage type 4

Dividing the four demand coverage types into 12 task coverage types and assign them to agents seems to increase the complexity of the planning process, especially from the optimization point of view. However, this method is currently used by the company because of two main reasons. First, no single agent group created by the four available full-time contracts (see Table 11) can cover the demands with coverage types 3 or 4. We suppose that if the company has two flexible part-time contracts in which agents with the first contract can work 8 hours a day 3 days a week and those with the second contract can work 8 hours a day 4 days a week, the company does not have to divide a demand with coverage type 3 into 6 task coverage types but only 2. The second reason for this demand-task decomposition is that once the work plan is created, it will be kept for a very long time, usually until the end of a client contract. Therefore, for the company planners, creating a work plan with a reasonably higher level of complexity once per year is still better than managing agents with flexible part-time contracts, who are not quite loyal to the company and thus can affect long-term workforce stability if their proportion in comparison to those with stable contracts is high.

The time windows and duration of a task depends on its coverage type (see Table 10). Moreover, the time windows are generally very strict. Its start time is fixed and its duration equals the time-window duration.

Required skill type: A required skill type is a combination of a service type and a workplace type. For example, if the service type is cleaning and the workplace type is a hospital, the required skill type will be hospital cleaning.

Table 10. Task coverage types decomposed from demand coverage types

Demand coverage type	Task coverage type	Number of weekly service days	First service day of the first week	Number of daily service hours	Daily start service time
1	1	5/7	Monday	8h/24h	8 am
2	2	6/7	Monday	8h/24h	8 am
3	3	5/6	Monday	8h/24h	8 am
3	4	5/6	Tuesday	8h/24h	8 am
3	5	5/6	Wednesday	8h/24h	8 am
3	6	5/6	Thursday	8h/24h	8 am
3	7	5/6	Friday	8h/24h	8 am
3	8	5/6	Saturday	8h/24h	8 am
4	9	7/7	Monday	12h/48h	8 am
4	10	7/7	Monday	12h/48h	8 pm
4	11	7/7	Tuesday	12h/48h	8 am
4	12	7/7	Tuesday	12h/48h	8 pm

Required skill levels: For each skill type, different skill levels are required. Generally, three basic skill levels are considered in the service-to-business domain: supervisor (level 2), leader (level 1), and normal worker (level 0). A group of several agents working on the same task should have a leader to manage it, and several groups of agents assigned to the same task need a supervisor.

Number of agents required for each skill level: for each skill level of the required skill type, a number of agents have to work in parallel to perform the task, between its start and end times. A client demand usually mentions the number of agents needed in each period of each day but does not precise which levels of skill and which numbers of agents of each level are needed. The company managers divide the demand, depending on its coverage type, into tasks (see Table 10) and based on the experience, they decide which skill levels and a number of agents of each skill level should be provided for each task. With task coverage types 1 and 2, the numbers of agents required for the task and the corresponding client demand are equal. Regarding demand coverage type 3, because a client demand is divided into 6 tasks with 6 different task coverage types (3-8, Table 10) and only 5 among these 6 types are active at each moment (see Figure 7), the number of agents required for each task equals that required for the client demand divided by 5. This implies that the number of agents required for each demand type 3 has to be a multiple of five. With demand coverage type 4, different from type 3, because each client demand is divided into 4 disjoint tasks (in sequence) of 4 different task coverage types and only 1 among these 4 is active at each moment, the number of agents required for each task, therefore, equals the number of agents required by the demand (see Figure 8).

4.2.3. Agent

For agents, we detail three important characteristics that include work contract type, skill types, and skill level for each skill type.

Contract type: Agents sign a shift or non-shift contract with the company, specifying their numbers of work hours per day, and workdays per week, and daily start, break and end times. The company is currently using three non-shift and one shift work contract types (see Table 11). An agent can be assigned to a task only if its contract type is compatible with the task coverage type (see Table 12). For all the contracts, their weekly days-off are not allocated in advance but decided during the assignment, depending on which tasks they are assigned to. Days-off of agents with contracts 5x2 and 6x1 are the same for all the weeks because their work schedule is defined per week. By contrast, the work schedule of agents with contracts 5x1 and 12x36 is defined per 6 days and per 2 days respectively, their days-off can, therefore, be different between weeks.

Table 11. Brazilian company's current contract types

Contract type	Shift or non-shift	Work time	Break time	Possible daily start time	Contract work time/ week	Number of work trips / week
5x2	Non-shift	5 consecutive days/week	2 days /week	Any time	40h	5
6x1	Non-shift	6 consecutive days/week	1 day /week	Any time	48h	6
5x1	Non-shift	5 consecutive days/6 days	1 day /6 days	Any time	46.7h	5.8
12x36	Shift	12h/48h	36h/48h	Any time	42h	10.5

Table 12. Compatibility between work contract types and task coverage types

Demand coverage type	1	2	3						4			
Task coverage type/ work contract type	1	2	3	4	5	6	7	8	9	10	11	12
5x2	1	0	0	0	0	0	0	0	0	0	0	0
6x1	0	1	0	0	0	0	0	0	0	0	0	0
5x1	0	0	1	1	1	1	1	1	0	0	0	0
12x36	0	0	0	0	0	0	0	0	1	1	1	1

1: compatible, 0: incompatible

Skill types: are types of skills that an agent has to perform tasks. Each agent can have several skill types. Each agent skill type corresponds to a skill type required by tasks.

Skill level of each skill type: For each skill type, an agent has a skill level corresponding to a required skill level of tasks (see Section 4.2.2). The skill level of a secondary skill type of an agent depends on his/her main skill type. For example, if the main skill type of an agent is hospital cleaning and his/her skill level is 2 (leader), he/she can also work as a leader for shop cleaning without difficulty. However, an agent mainly working in a shop, restaurant, or factory, may find it difficult to work in a hospital.

4.2.4. Travel route

For the definition of the characteristics of the travel route, see Section 2.2.4. Besides, in this chapter, because we assume that each active agent stays in the same client's workplace during a day, he/she, therefore, makes a maximum of two single commute trips including one from his/her home to the workplace and the other one from the workplace back home. Moreover, because we assume that the travel cost and time are the same for these two single trips, the travel cost and time of a round trip are, therefore, two times of those of a single trip. The travel route can be, therefore, identified by the agent ID and the client ID instead of the site ID 1 and site ID 2 in Section 2.2.4.

4.3. Local planning for new clients and agents

In this section, we consider the first level of our two-level planning approach, local planning for a group of new clients, and newly recruited agents. First, we present the method used to model and solve the problem. Then, we perform some numerical experiments with real data to assess the performance of the method proposed.

4.3.1. Problem modeling

We use the mixed integer linear programming method (MILP) to model and solve the problem. A mathematical modeling and solving approach like MILP appears to be a reasonable choice to investigate the problem characteristics in comparison to approximation methods. Concerning the local planning problem, because we want to consider two different objectives, the MILP method becomes the multi-objective MILP method. In comparison to the mono-objective optimization, the multi-objective optimization allows finding a single solution with the best compromise between different objectives. Common techniques used to deal with the multi-objective MILP are the weighted sum, weighted Tchebycheff, ε-constraint, and lexicographic methods. The definitions of these methods are presented in Appendix B. The weighted sum (Soland, 1979) and weighted Tchebycheff (or weighted metric) methods (Bowman, 1976) are weight-based methods that are simple but quite efficient and thus, commonly found in the literature. The difference between these two methods is that the weighted sum method is not quite efficient in the case of a nonconvex objective space while the weighted Tchebycheff method is used for both convex and nonconvex spaces. However, the weight Tchebycheff method requires the minimization of individual single-objective optimization problems to determine the utopia points, which can be computationally expensive (Arora, 2012). Similar to the weighted Tchebycheff method, the ε-constraint method can be used for convex and nonconvex objective spaces. However, the idea behind this method is different; it keeps only one of the objectives and restricts the others within user-specific values ε (Mavrotas, 2009). The advantage of this method is that it permits producing non-extreme efficient solutions, which are not allowed by the weighted-based methods (Mavrotas, 2009). However, this method is not quite efficient for the problems with more than two objectives, and choosing the range of the objective functions ε may require researchers with experience (Mavrotas, 2009). The lexicographic method is the simplest technique dealing with the multi-objective problem. A pre-defined order of objectives is established and then, a sequence of single-objective optimization problems is solved (Stanimirovic, 2012). This means that each objective is optimized at a single point of time (Stanimirovic, 2012). The disadvantage of this method is that the decision-maker needs to determine the preferences for the objectives to establish the lexicographic order, which can be a difficult task (Stanimirovic, 2012).

We choose to use the weighted sum method, which is simple but quite efficient to deal with our multi-objective MILP model. The weight of each criterion in the multi-objective formulation can be variable and depends on the importance of each objective considered by the company.

In this section, we propose a bi-objective MILP model for the local planning that considers a group of new clients and newly recruited agents. Indices, parameters, variables, objectives, and constraints of the model are given below.

4.3.1.1. Indices

- Agents: {1,..,i,..,N}
- Tasks: {1,..,j,..,J}
- Skill types: {1,..,k,..,K}
- Skill levels: {1,..,q,..,Q}

4.3.1.2. Parameters

- N: Number of available agents
- J: Number of tasks
- K: Number of skill types
- Q: Number of skill levels
- TT_{ij} : Travel time of the round trip between addresses of agent i and task j
- TC_{ij} : Travel cost of the round trip between addresses of agent i and task j
- NBA_{jkq} : Number of agents having skill type k level q required by task j
- NB_j : Total number of agents required by task j, $NB_j = \sum_{k=1}^{K}\sum_{q=1}^{Q} NBA_{jkq}$
- NBT_i : Number of round trips per week that agent i has to take. The number of round trips that an agent takes per week depends on his/her contract type (column 7, Table 11). In order to avoid using another index for contract types, we use agent index i here.

- $CPAT_{ij}$: Compatibility between work contract of agent i and coverage type of task j, =1 if compatible, =0 otherwise
- SA_{ikq}: Skill type and level of an agent, =1 if agent i has skill type k level q, =0 otherwise

4.3.1.3. Variables

- x_{ij}: =1 if agent i is assigned to task j, =0, otherwise

4.3.1.4. Objective function

$$\text{Minimize } \alpha\Pi_{TC} + \beta\Pi_{TT} \tag{1A}$$

- The average weekly travel cost per agent:

$$\Pi_{TC} = \frac{1}{N}\sum_{i=1}^{N}(NBT_i \times \sum_{j=1}^{J}(TC_{ij} \times x_{ij})) \tag{2}$$

- The average work trip duration per agent:

$$\Pi_{TT} = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{J}(TT_{ij} \times x_{ij}) \tag{3}$$

The MILP model for the local planning problem considers two different objectives in a weighted sum formulation (1A), including minimizing the average weekly travel cost per agent between their home and workplace (2) and maximizing agents' satisfaction by minimizing their average work trip duration (3). The travel costs are considered over a week, taking into account the number of round trips each agent has to take, while the work trip duration is considered over a round-trip. This is because each agent has a different work contract type with a different number of work trips per week. This difference affects the total amount of money the company has to refund to its agents each week and so, is important for our problem. In terms of the average trip duration, this difference does not affect agents' satisfaction. The factor that really affects their satisfaction is the duration of each round trip that they spend between their home and workplace.

4.3.1.5. Constraints

$$x_{ij} \le CPAT_{ij}, \ \forall i = 1..N, \forall j = 1..J \tag{4}$$

$$\sum_{j=1}^{J} x_{ij} = 1, \forall i = 1..N \tag{5}$$

$$\begin{cases} \sum_{i=1}^{N} SA_{ikq} \times x_{ij} \geq NBA_{jkq}, \forall j = 1..J, \forall k = 1..K, \forall q = 1..Q \\ \sum_{i=1}^{N} x_{ij} = NB_j, \forall j = 1..J \end{cases} \tag{6}$$

Equations (4) ensure the compatibility between the agent work contract type and task coverage type, for example, an agent with work contract type "5x2" can only be assigned to a task having task coverage type "5x2". Equations (5) ensure that each agent has to be assigned to exactly one task. Equations (6) imply that for each skill type and skill level, the number of agents assigned to a task has to equal the number of agents required by that task. The first set of these equations uses inequalities instead of equalities because some agents may have a skill level for some skill types that are not exploited by the task (multi-skilled agents). Thus, these inequalities allow the number of agents of each skill type and skill level assigned to a task to be greater than the number of agents it requires. The second equation set of (6) is added to ensure that these numbers are equal.

4.3.2. Experiments

These experiments are not the core of our study. With these experiments, we aim at studying the ability of our model in creating initial plans for new clients. These plans will then be used for our core experiments (in Section 4.4) to compare the solutions obtained by the one-level planning approach which is an aggregation of the local plans and those obtained by the two-level planning approach.

4.3.2.1. Data

The data used to test and assess the mathematical model are part of a big database of the Brazilian company that is providing services to businesses in more than 200 municipalities of four Brazilian states. The database, regrouping all the currently active agents and clients of the company, consists of 4781 agents and 1261 tasks. The data selected for this study are the data of the Sao Paulo metropolitan – the biggest metropolitan regarding numbers of agents and tasks in the database (672 agents and 141 tasks).

Most of the data used for experiments are accurate data, provided by our Brazilian partner, except the travel costs and travel times, which have been approximated. We divided the Sao Paulo metropolitan into 13 smaller zones; the average travel cost and time of a single trip between any two zones were calculated by google map[19], using their center points as the starting point and destination, and the public transport as the transport mode. The agent travel cost between any two zones was assumed to be the average travel cost between these zones. The travel time was differently generated by a normal distribution whose expected value equals the average travel time between the two zones and standard deviation is 10% of the expected value. Besides, we performed a test on the correlation between these two matrices of travel costs and travel times. Their calculated correlation coefficient is 0.35, which means that the two matrices are positively correlated, but only to a limited extent, and that travel costs and travel times are not proportional.

Below is the summary of basic information about the database:

- Number of available agents: 672
- Number of tasks: 141
- Number of skill natures: 3 (cleaning, concierge, and surveillance)
- Number of task workplace types: 6 (hospital, factory, shop, office, university, and jointly-owned residence)
- Number of skill types: 18 (3 skill natures x 6 workplace types)
- Number of skill levels: 3 (supervisor, leader, and normal worker)
- Number of work contract / demand coverage types: 4 (5x2, 6x1, 5x1, and 12x36) (see Table 11 and Table 12)

We use 30 sets of eight different instances to perform experiments. Each instance allows for generating a local plan. A set of eight instances results in a global plan. The numbers of tasks and agents of each instance were chosen between 7 and 10 and between 35 and 50 respectively. This means that the size of the total numbers of tasks and agents of each set of 8 instances is about half the size of the benchmark (~70 tasks and 350 agents).

Each set of instances was generated as follows: we randomly picked up a number of tasks between 7 and 10 and obtained associated agents from the manual planning provided by our

[19] https://maps.google.com

partner. If the number of agents was between 35 and 50, we kept this instance; otherwise, we removed it and picked up another instance. Once the instance was chosen, the tasks and agents associated with it were removed from the manual planning to ensure that they will not reappear in the next pick-up for another instance of the same set.

Doing things like this can ensure that the tasks and agents of each instance of the same set are different, which reflects the realistic situation of companies when they have, in each time span, some new client contracts and some available agents to cover these contracts and these clients and agents are different from those in other time spans. Moreover, because the size of each set of instances is only half size of the benchmark and the tasks and agents of each set are picked up randomly from the benchmark, the tasks and agents of each set will be generally different from those of any other sets. The diversity of the 30 sets of instances can, therefore, be ensured.

4.3.2.2. Experiment results

We use the CPLEX Studio IDE of IBM[20], installed on an ordinary computer (laptop Acer Aspire V13-chip core i5 6200U), to solve the problems. The calculation time needed to find the optimal solution for each local planning is very small (less than one second). This shows the efficiency of our model in solving small-size local planning problems (about 8 tasks and 40 agents).

To perform experiments, for each of the eight instances of each set, we solve three problems, which include two mono-objective problems with TC (average weekly travel cost per agent) and TT (average work trip duration per agent), and one weighted sum bi-objective problem. Solving the two mono-objective problems, we obtain the two corresponding optimal values MTC* and MTT* and the two problem solutions. Based on the solution of the first problem, we calculate the TT value (called MTT). Similarly, we obtain the TC value for the second problem (called MTC). For the third problem, in order to ensure the same contribution of each criterion (TC and TT) on the global objective, the weight coefficients alpha (of TC) and beta (of TT) of the weighted sum formulation of the MILP model are chosen to be 1/MTC* and 1/MTT* respectively. Solving this weighted sum bi-objective problem, we obtain the two optimal values WTC* and WTT*. After

[20] https://www.ibm.com/fr-fr/products/ilog-cplex-optimization-studio

that, we calculate percentages of improvement of the two criteria when using the bi-objective formulation in comparison to mono objective formulations as follows:

% improvement of TC (mono TC as reference) = - (WTC*- MTC*) x 100% / MTC*

% improvement of TT (mono TC as reference) = - (WTT*- MTT) x 100% / MTT

% improvement of TC (mono TT as reference) = - (WTC*- MTC) x 100% / MTC

% improvement of TT (mono TT as reference) =- (WTT*- MTT*) x 100% / MTT*

Finally, the average percentage of improvement for each of the 30 sets of instances is the average value of the percentages of improvement of all the eight instances of the set.

The experimental results (Table 13) show that in comparison to the mono-objective formulation with TC or TT, using the weighted sum bi-objective formulation gives a solution with a better compromise between the two objectives. On average, a small loss of 0.8% of TC (resp. 0.8% of TT) in comparison to the mono-objective formulation with TC (resp. with TT) can be recompensed by a significant gain of 2.5% of TT (resp. 3.3% of TC). The orders of magnitude are found pretty much the same for the instances with the best and the worst sums of loss and gain. These results confirm that the gain is always larger than the loss when using the multi-objective formulation for any instance. In other words, the multi-objective problem always gives a better compromise between the criteria considered than the mono-objective formulations.

These experiments are necessary to evaluate the efficiency in solving the local planning model but they are not the core of our experiments. The results will be used in Section 4.4 to evaluate the performance of solutions obtained by two-level planning, which includes both the local and global planning.

Table 13. Criteria's relative changes considering bi- versus mono-objective planning

Mono-objective formulation used as reference	Mono TC		Mono TT	
Instance set	% of improvement of TC	% of improvement of TT	% of improvement of TC	% of improvement of TT
1	-0.9%	3.0%	5.6%	-2.1%
2	-0.5%	1.9%	2.8%	-0.4%
3	-1.4%	2.9%	4.0%	-1.1%
4	-0.9%	4.6%	1.8%	-0.3%
5	-0.8%	3.0%	4.6%	-0.8%
6	-0.5%	1.6%	2.3%	-0.4%
7	-1.5%	3.1%	2.5%	-0.8%
8	-0.9%	1.8%	2.8%	-0.5%
9	-0.3%	1.4%	6.4%	-2.2%
10	-0.5%	0.8%	0.4%	-0.1%
11	-0.8%	1.5%	4.5%	-0.9%
12	-1.0%	1.9%	1.4%	-0.5%
13	-1.3%	3.5%	1.1%	-0.3%
14	-0.6%	1.9%	1.1%	-0.5%
15	-1.2%	3.4%	3.2%	-0.6%
16	-0.5%	1.6%	2.5%	-0.8%
17	-1.7%	3.9%	4.6%	-1.4%
18	-1.2%	2.3%	9.4%	-3.1%
19	-0.8%	2.5%	0.8%	-0.4%
20	-0.5%	2.3%	3.6%	-1.1%
21	-0.6%	2.1%	3.6%	-0.5%
22	-0.4%	2.4%	3.3%	-0.6%
23	-1.0%	4.0%	1.0%	-0.4%
24	-0.2%	2.1%	3.1%	-0.6%
25	-0.8%	1.9%	5.3%	-0.9%
26	-0.9%	2.0%	4.0%	-0.8%
27	-1.3%	2.1%	3.8%	-0.7%
28	-0.9%	2.2%	4.7%	-0.9%
29	-0.4%	1.5%	2.6%	-0.7%
30	-0.8%	5.0%	1.1%	-0.5%
Average	**-0.8%**	**2.5%**	**3.3%**	**-0.8%**

4.4. Global planning for all active clients and agents

Currently, the Brazilian company manually generates a schedule for each client independently of the others and never questions it. In Section 4.3, we showed the interests of the first planning level of our two-level planning approach, to create the initial plans for a set of new clients. In this section, we aim at investigating the interests of the second planning level, global planning. The aggregation of local plans obtained by the local planning approach will be compared with a new global plan obtained by the global planning approach.

Later in this section, we introduce the model and the resolution method used to solve the global planning problem (Section 4.4.1). Then, we perform some numerical experiments to assess the performance of the method proposed. Firstly, Section 4.4.2 evaluates the solutions obtained by the two-level planning in comparison with the single-level planning. Secondly, Section 4.4.3 aims at comparing the work plans obtained by our global planning approach and the current work plans manually created by the company's planners.

4.4.1. Model and resolution method

The MILP model for global planning shares many common characteristics with the MILP model for local planning. There are only two main differences between them. First, the model for the local planning uses (1A) as the bi-objective function which includes minimizing the average weekly travel costs between agents' homes and their workplaces and minimizing their average trip duration. The model for global planning uses (1B) as the mono-objective function, which is minimizing the average weekly travel costs between agents' homes and their workplaces. However, a set of constraints (7) is added to ensure that the trip duration of each agent obtained in the new planning has to be at least as good as his/her trip duration in the most recent planning, which requires the introduction of a new parameter. These constraints ensure the satisfaction of agents who do not want to spend more time traveling than what they were used to.

LTT_i : The trip duration of agent i in his/her most recent work plan before this global planning

$$\text{Minimize } \Pi_{TC} \tag{1B}$$

$$TT_{ij} \times x_{ij} \leq LTT_i, \forall i = 1..N, \forall j = 1..J \quad (7)$$

4.4.2. Two-level planning vs one-level planning

The aim of the experiments is to compare the solutions obtained by our two-level planning approach, which includes local planning and global planning, and those obtained by using one-level planning only. By analyzing the potential gains in terms of costs and time, these experiments help us assess the interests of the second planning level.

4.4.2.1. Data

The benchmark used in this section is the same as that in Section 4.3, which is provided by the Brazilian company. We use a total of 30 instances to perform the experiments. These 30 instances correspond to the 30 sets of instances used for the experiments of the local planning (see Section 4.3.2.1). Each instance of the global planning is created by aggregating all the clients and agents of the eight instances of the corresponding instance set used for the local planning. Moreover, our instance generation method ensures that any two instances of the same set do not contain the same clients or agents. By doing so, we supposed that all the clients and agents of the local planning are still active at the time we consider global planning.

4.4.2.2. Experiment results

Similar to the resolution of the local planning model, we use the CPLEX Studio IDE of IBM installed on an ordinary computer (laptop Acer Aspire V13-chip core i5 6200U) to solve the global planning problem. The calculation time needed for each experiment is very short (less than one second).

We use in total 30 “global” instances which correspond to 30 sets of eight “local” instances to perform experiments. For each of the eight “local” instances of the corresponding instance set, the optimal solution obtained when we solved the bi-objective weighted sum model (see Section 4.3) allows us to calculate the weekly travel costs and trip duration of each agent. The average weekly travel costs per agent (LTC) and the average trip duration per agent (LTT) of each “local” set of eight instances equal the average values of the weekly travel costs and the trip durations of all the agents of all the eight “local” instances of the set. For each “global” instance, we first solve the mono-objective global planning model, proposed in Section 4.4.1. The parameter LTT_i of the model, which represents the trip duration of each agent in his/her previous plan, is provided by the local planning. By solving the model, we obtain the optimal value of the unique criterion considered, the average weekly travel cost per agent (GTC). Besides, based on the solution obtained, we calculate the trip duration between the home and workplace of each agent and thus, the average trip duration per agent (GTT). Percentages of improvement of the two considered criteria (TC and TT) obtained by the global planning (GTC, GTT) in comparison to those of the local planning (LTC, LTT) given Table 14, are calculated as follows:

% of improvement of TC = -(GTC-LTC) x 100% /LTC

% of improvement of TT = -(GTT-LTT) x 100% /LTT

The results show that, in comparison to the single-level planning, the two-level planning slightly improves both the criteria considered (TC and TT) on average by 2% and 4.2% respectively (the last two cells of the last row, Table 14). The maximum percentages of improvement that can be obtained for TC and TT are 4.5% and 5.8% respectively (Two cells in green color, Table 14). These improvements are neither big nor negligible. Besides, the minimum percentages of improvement are 0.5% for TC and 2.7% for TT (Two cells in red color, Table 14). This means that the solutions obtained by the two-level planning are always better than those of the one-level local planning for both criteria considered. This conclusion can be explained by the way that we use the MILP method. The unique mono-objective formulation of the global planning model (1B) ensures that, in comparison to the local planning, the global planning always obtain globally optimal weekly travel costs for all the agents of the instance set, which is obviously better than the aggregation of the locally optimal weekly travel costs for each instance of the set. Also, because global planning and local planning consider the same number of agents, the average weekly travel costs per agent are, therefore, always better when using global planning. Moreover, the constraints (7) of the global planning model ensure that the trip duration of each agent created by global planning has to be at least as good as that of the previous planning. Because for the two-level planning, the previous planning is the local planning, the trip duration per agent of the two-level planning is, therefore, always at least as good as that of the local planning. Briefly, the two-level planning always gives a solution with both better criteria than the one-level planning.

Table 14. Criteria considering one-level versus two-level planning

Set of instances	One-level planning(*)		Two-level planning(**)		Improvement of (**) versus (*)	
	TC (R$)	TT (minutes)	TC (R$)	TT (minutes)	TC (%)	TT (%)
1	289.1	144.6	284.6	136.9	1.6	5.3
2	302.2	142.2	294.7	134.3	2.5	5.5
3	268.0	136.0	262.1	130.9	2.2	3.7
4	295.4	132.6	290.6	126.2	1.6	4.9
5	277.9	139.5	272.3	133.0	2.0	4.7
6	292.6	135.1	289.5	130.4	1.1	3.5
7	295.9	142.7	289.0	135.5	2.3	5.1
8	300.6	137.4	299.1	133.7	**0.5**	**2.7**
9	297.1	144.2	289.6	136.5	2.5	5.4
10	290.2	143.7	280.7	137.6	3.3	4.2
11	282.4	142.4	273.8	134.5	3.0	5.6
12	286.3	150.8	277.0	145.3	3.2	3.6
13	272.5	148.1	265.1	143.5	2.7	3.1
14	284.5	138.4	281.5	134.1	1.1	3.2
15	304.5	147.7	298.5	140.0	2.0	5.2
16	278.9	136.4	275.3	132.5	1.3	2.8
17	278.9	134.3	273.5	127.2	1.9	5.3
18	296.8	149.2	290.4	141.0	2.2	5.5
19	275.7	137.7	266.2	131.0	3.5	4.9
20	286.4	138.0	283.5	133.3	1.0	3.4
21	277.3	141.9	271.7	137.3	2.0	3.3
22	283.5	144.5	280.7	140.1	1.0	3.0
23	300.9	131.2	297.1	125.2	1.3	4.6
24	292.3	140.8	290.1	136.2	0.8	3.2
25	274.2	151.9	267.3	143.1	2.5	**5.8**
26	279.7	143.5	277.6	138.1	0.8	3.7
27	300.9	139.3	295.3	134.5	1.9	3.5
28	276.8	145.4	264.3	137.9	**4.5**	5.2
29	293.3	150.1	282.1	145.3	3.8	3.2
30	295.8	131.6	291.2	126.4	1.6	3.9
Average	**287.7**	**141.4**	**281.8**	**135.4**	**2.0**	**4.2**

4.4.3. Global planning vs manual planning

The objective of these experiments is to compare the quality of the solutions obtained by our global planning model and the current manual "local" planning of the company. The unique plan for all the clients and agents of the company until now is an aggregation of several “local” plans, obtained by the manual “local” planning approach. Each “local” plan considers a group of clients and agents whose contracts arrive in the same time span.

4.4.3.1. Data

We use only the unique real instance, the benchmark provided by our Brazilian partner to perform the experiments. This benchmark is the manual “global” plan of all the active clients and agents of the company. The numbers of clients (and so tasks) and agents considered in this plan are 141 and 672 respectively. The trip duration of an agent in the most recent planning that is used as the input data for our global planning model is assumed to be his/her trip duration of the corresponding “local” plan obtained by the manual planning.

4.4.3.2. Experiment results

The optimization solver and the parameters used for the experiments in this section are the same as those used for the local planning in Section 4.3.2. The calculation time needed to find the optimal solution is also very small (several seconds).

To perform the experiments, we first solve the mono-objective global planning model with the unique instance to obtain the optimal value of the average weekly travel costs per agent (GTC) and the corresponding solution. This solution allows us to calculate the trip duration of each agent and thus, the average trip duration per agent (GTT). On the other hand, the manual “global” plan of the company allows us to calculate the weekly travel costs and trip duration of each agent, which are used to obtain the average weekly travel costs per agent (MTC) and the average trip duration per agent (MTT). Finally, the percentages of improvement of the two criteria (TC and TT) are calculated as follow:

% of improvement of TC = -(GTC-MTC) x 100% /MTC

% of improvement of TT = -(GTT-MTT) x 100% /MTT

The experiment results (Table 15) show that the two criteria considered (TC and TT) are significantly improved when using global planning in comparison to the manual planning provided by the company. Percentages of improvement for the average weekly travel costs per agent and the average trip duration per agent are 7.1% and 10.9% respectively. These quite high percentages show the interest of globally reconsidering the decisions taken. Further experiments should be performed to verify this possibility.

Table 15. Criteria considering manual planning versus our global planning

Objective formulation	Criterion	Manual planning(*)	Our global planning(**)	Improvement of (**) versus (*)
Mono TC	TC (R$)	301.9	280.4	7.1%
	TT (minutes)	144.1	128.4	10.9%

4.5. Conclusion

In this chapter, we investigate the work team building and planning problem in the service-to-business domain and context of stable demand. This problem corresponds to the real situation of the Brazilian company. Because the company currently solves the problem manually, different decomposition techniques have been used to simplify the planning process. The work contract and task decomposition technique, currently used by the company, limits the number of task types that an agent with a certain work contract type can perform. This technique is generally quite efficient in the context of stable demand. The company is creating a “local” plan for each group of new clients and newly recruited agents of the same time span (3 weeks). The total plan for all the clients and agents is an aggregation of all the “local” plans. This way of planning keeps the agent-client assignment fixed until the end of their contracts and therefore, ensures the agent work efficiency. However, it does not take advantage of re-planning that can reduce both the company’s costs and agents’ travel time.

We proposed in this chapter a two-level planning approach that includes local and global planning. The local planning is used to create, every short duration, initial work plans for new clients, and newly recruited agents. The global planning, created every long duration, provides new work plans for all the active clients and agents who have been together for at least a certain duration.

Two mixed-integer linear programming models were developed that allowed us to perform some numerical experiments on the real database provided by our Brazilian partner. The optimal solutions were obtained within seconds for both local planning and global planning, which shows the efficiency of our modeling and solving approach for problems with a real size (672 agents and 141 tasks). The experimentation results show the superiority of our local/global planning in comparison to the manual planning of the company. Our local planning gives the optimal solution with a better compromise between the two criteria considered, which include the average weekly travel costs per agent (TC) and agents' satisfaction related to their average trip duration (TT). Our global planning gives both better criteria TC and TT in comparison to the company's manual planning by 7.1% and 10.9% respectively. Besides, the experiments also show the interest of our two-level approach in comparison to an aggregation of successive work plans obtained by only the local planning, and without changing the agent-task assignments. The average percentages of improvement for TC and TT are 2% and 4% respectively.

In this chapter, the work contract and demand coverage type decomposition was used. Agents and demands are divided into groups according to their work contract types and demand coverage types. Each agent can only be used to cover certain demand coverage types. This technique helps simplify the planning process significantly, especially for the manual planning that the company is using. However, the efficiency of this technique significantly depends on the number of available contracts. With the four current agent work contracts, the company cannot cover new demand coverage types that are required more and more by their clients. These include small demands required for only 4 hours per day, several days per week, and variable demands required with different numbers of days per week, for example, 5 days one week, 6 days another week, and 7 days another week. These cases will be the subject of Chapter V- the work team building and planning problem in the service-to-business domain and context of variable demand.

Chapter V. Work team building and planning problem in the service-to-business domain and context of variable demand

Résumé en français

Dans ce chapitre, nous considérons le problème de constitution et de planification d'équipes de travail dans le domaine du service aux entreprises et un contexte de demande variable. Nous étudions, deux leviers organisationnels et trois manières différentes de modéliser la dépendance entre les horizons de planification, pour augmenter le niveau d'adaptation de la main-d'œuvre afin de couvrir ces demandes variables. Les deux leviers comprennent l'introduction de deux nouveaux contrats de travail flexibles et la considération d'agents polyvalents. Les trois manières de modéliser la dépendance entre les horizons de planification comprennent les cas indépendant, dépendant « pur », et notre proposition dépendant avec zones tampons.

L'entreprise souhaite atteindre trois objectifs différents : minimiser les coûts de déplacement des agents (TC), maximiser l'équité de la charge de travail entre les agents (MC), et enfin, maximiser leurs préférences pour les périodes de travail (PR). La méthode de programmation linéaire mixte a été utilisée pour modéliser et résoudre quatre problèmes différents, dont trois problèmes mono-objectifs, avec TC, MC et PR comme objectif respectivement, et un problème multi-objectif (somme pondérée des 3 critères). Trente instances réalistes, construites sur la base de données réelles fournies par notre partenaire brésilien, ont été utilisées pour effectuer des expériences numériques.

Les résultats montrent que notre méthode de résolution est capable de résoudre des problèmes d'une certaine taille réaliste, pour lesquelles le nombre de clients est inférieur ou égal à 6, le nombre de tâches journalières (différentes des tâches de longue durée considérées au Chapitre IV) est inférieur ou égal à 100 et le nombre d'agents est inférieur ou égal à 60. En termes de qualité des solutions obtenues, la considération d'agents polyvalents améliore légèrement les trois critères considérés, à la fois pour les problèmes mono-objectifs et multi-objectifs. L'introduction de deux nouveaux contrats de travail donne un meilleur compromis entre ces trois critères. Elle dégrade légèrement TC, mais améliore légèrement MC et significativement PR, à la fois pour les problèmes mono-objectifs et multi-objectifs. Enfin, les

temps de pause et les zones tampons flexibles augmentent la chance de trouver une solution faisable par rapport à la méthode de planification actuelle de l'entreprise. En plus, ces considérations donnent des solutions avec un meilleur compromis entre les critères considérés par rapport au cas indépendant qui est couramment considéré dans la littérature, hypothèse de simplification irréaliste selon laquelle toutes les ressources nécessaires sont disponibles dès le début de l'horizon de planification.

In this chapter, we investigate the problem in the context of variable demand and for a shorter planning horizon. This problem and that in chapter 4 are considered separately because of two main reasons. First, they have two different levels of criticality, one corresponds to the current situation of a company and the other is a potential problem in the future that the company will have to deal with. Second, the work plan can be created for a long horizon in the case of stable demand by cyclic planning, which generates a work plan for a short duration and then repeats it as many times as clients are still active. By contrast, the work plan can be created only for a short horizon and without repetitiveness in the case of variable demand. Then, to cover new variable demand, the workforce organization has to be changed, the demand and workforce modeling become, therefore, more complex. When the demand is variable, we have to care about agents' satisfaction related to their fluctuating workload between planning horizons and their preferences for certain work periods, which increases the complexity of the modeling and solving approach.

A preliminary version of this chapter gives the materials for a conference paper (Doan et al. 2019b).

5.1. Introduction

In this chapter, we consider a demand with realistic and moderate variability, which may be the most probable scenario in the near future of our Brazilian partner. To answer new variable demand and to take advantage of labor reforms introduced by the governments to combat unemployment recently, we propose to focus on flexible full-time and part-time contracts.

In the service-to-business domain, agents usually have a fixed cycle of work and break times, which reduces their flexibility. We propose to allow them to have flexible break time between consecutive sets of work times. Moreover, the dependence of agents' activities between consecutive planning horizons is another reason for workforce inflexibility. Companies are generally considering the "fully" dependent case while academic researchers generally consider the independent case (see Section 3.3.2). We propose to consider a new approach "dependent with buffer zones", which is an intermediate between the independent and "fully" dependent. The dependent with buffer zones and the permission of flexible break time between consecutive sets of work times presented above are inspired by the idea of "buffer zones" commonly found in the job/flow shop scheduling (Lin, Liu, and Chen 2020; Liu and Kozan 2016).

Regarding agents' extra hours, we propose to consider the overtime under annualized work hours, in which agents are allowed to work a certain number of hours more or less than their contract work time, depending on the real demand of the horizon. The difference between agents' real work time and contract work time at the end of the year is considered as the agents' extra hours if it is positive.

Of the five levers commonly used in reality and in the literature to increase workforce adaptation, the use of extra agents can be simplified in a way that only a fixed and realistic proportion of these agents is considered. The use of the agents' extra hours is included in the objective modeling. The consideration of flexible break time between consecutive sets of work times is integrated in the third way to model the dependence between planning horizons, dependent with buffer zones. We, therefore, only focus on the investigation of the two levers (flexible work contracts, and the use of multi-skilled agents) and three ways to model the dependence between planning horizons (independent, "fully" dependent, our proposition - dependent with buffer zones).

In Section 5.2, we present the problem characterization. In Section 5.3, we propose a mixed-integer linear programming method (MILP) for solving the problem, with three different sets of constraints to model the three types of dependence between planning horizons. Section 5.4 introduces real data used to generate instances for experiments and the experiment methodology. In Sections 5.5 and 5.6, we perform some numerical experiments to evaluate the impact of the two levers proposed and the three types of dependence between planning horizons, respectively, on the feasibility and complexity of problem solving and the quality of the solutions obtained. Finally, Section 5.7 provides some conclusions of the chapter and perspectives for future research.

5.2. Problem characterization

The problem is characterized through the planning horizon (Section 5.2.1) and the four classes of objects: the clients, the demands (tasks), the agents, and the travel routes (Section 5.2.2).

5.2.1. Planning horizon

When the demand is variable, the planning horizon should be considered short. We consider a planning horizon of one week with seven workdays (Figure 9).

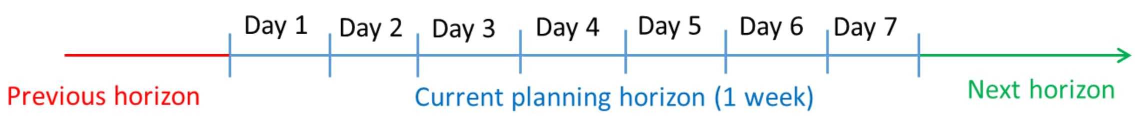

Figure 9. A one-week planning horizon of seven days

In our research, a workday in a planning horizon consists of 24 hours, starts at 4:00 a.m., and is divided into 6 periods of 4 hours each (Figure 10). The duration of tasks is assumed to be a multiple of 4 hours that corresponds to an integer number of periods. Any required task has to start and end within a day; we do not consider inter-day tasks. Agents performing tasks of at least 8 hours can take a flexible break of 30 minutes, depending on their workload. This means that this break time is included in the task duration and will not be discussed further in the chapter.

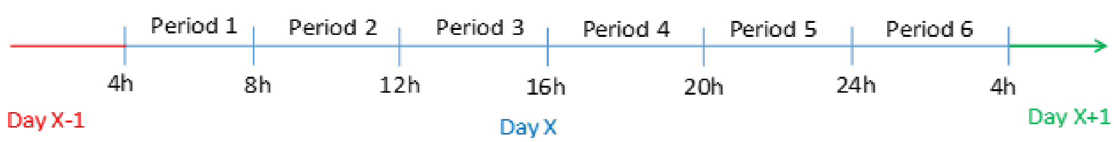

Figure 10. Periods of a day on a planning horizon

Any planning horizon has a link with the previous and the next ones. We consider three different types of dependence between them: independent, "fully" dependent, and dependent with buffer zones.

- The independent case considers that the availability of an agent in the current planning horizon is independent of his/her activities in the previous horizon, the only relationship is the modulation work time accumulated from one horizon to the next and measured by a modulation counter. In the literature, it is a simplification approach commonly used for academic research. However, this approach may be not realistic, an agent always needs a certain amount of break time between the end of an activity in the previous horizon and the beginning of another one on this horizon.

- In contrast to the independent, the "fully" dependent considers that the availability of an agent on the current horizon completely depends on what he/she did on the previous planning horizon. Aside from the modulation counters, we also have the constraints between the last workday and period, as well as the last day off of the agent in the previous planning horizon, and those on the current horizon. This type of dependence is very realistic but also quite constrained and thus limits the possibilities enormously. By considering these additional constraints, we can end up with problems without any solution meeting all the constraints.

We propose a new consideration, the dependent case with buffer zones, which is based on the "fully" dependent case, but with the addition of buffer zones between the last agents' activities on the previous planning horizon and their first activities on the current horizon. These buffer zones allow agents to have a flexible break between two consecutive activities in two successive planning horizons; it can reduce the constraints between their availabilities in these two horizons. This approach is quite realistic when it respects a certain duration of break time between consecutive activities of two planning horizons and less constrained than the "fully" dependent case where the duration of break is flexible.

Below, we give an example of the three types of dependence between planning horizons for an agent of work contract 12x36 existing at the Brazilian company (Figure 11). This type of agent has a work cycle of 48 hours, including 12 consecutive work hours and 36 consecutive break hours. We suppose that his/her last work shift in the previous planning horizon is between periods 1 and 3 of day 7. For the independent case, in this current horizon, the agent can start working in any period of day 1 or 2 for example (see Figure 11). In the "fully" dependent case, he/she has to take exactly 36 hours of break time before starting his/her work that is to say in period 1 of day 2. In the case of dependent with buffer zones, a buffer zone with a flexible duration is added right after the end of 36 hours of break time. For example, if we choose 12 hours (3 periods) as the maximum duration of the buffer zone, the agent can start his shift in periods 1, 2, 3, or 4 of day 2.

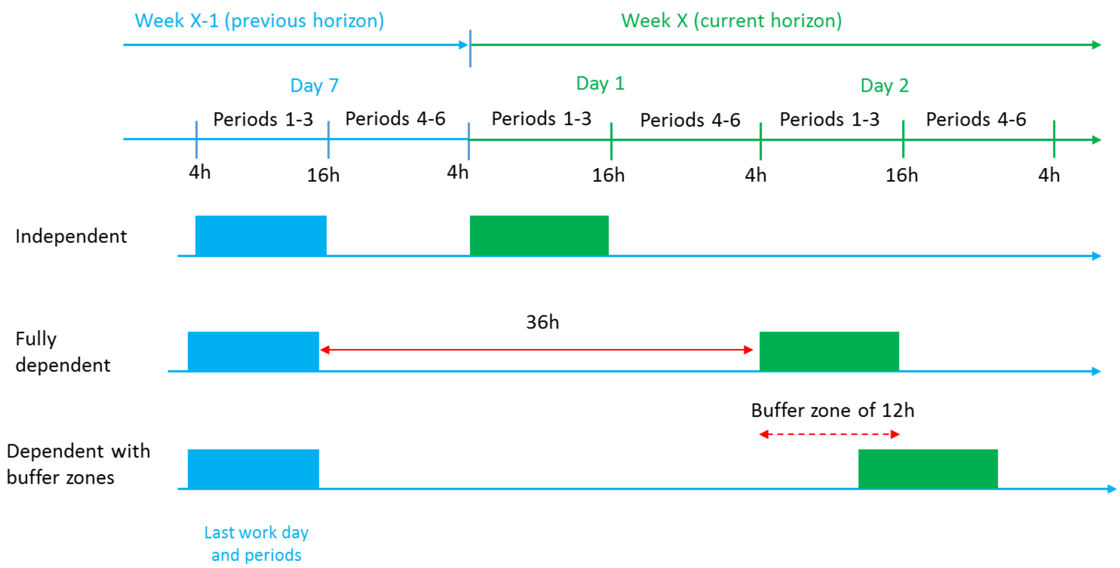

Figure 11. Example of three types of dependence for an agent with contract 12x36

5.2.2. Classes of objects associated with the problem

In this section, we consider four classes of objects that describe the problem, presented in the class diagram (Figure 12) and including the clients, tasks, agents, and travel routes. This class diagram is a particular case of the class diagram of the generalized problem (Section 2.2). Some characteristics of this problem are the same as those considered in the “generalized” problem (Section 2.2) or the problem with stable demand (Section 4.2) and will not be reintroduced here. We focus only on some special characteristics of this case study.

5.2.2.1. Client

See Section 4.2.1

5.2.2.2. Task

- Task ID, client ID, required day, required skill type, required skill levels, number of agents required for each skill level: see Section 4.2.2
- Daily repetitiveness: see Section 2.2.2.
- Duration: see Section 2.2.2. Moreover, because we assume that the task unit is 4 hours, the task duration is defined by the number of periods. The biggest task size that can be considered is 24h corresponding to 6 periods.

- Time-windows: see Section 4.2.2 for Task coverage type and Section 2.2.2 for Task.

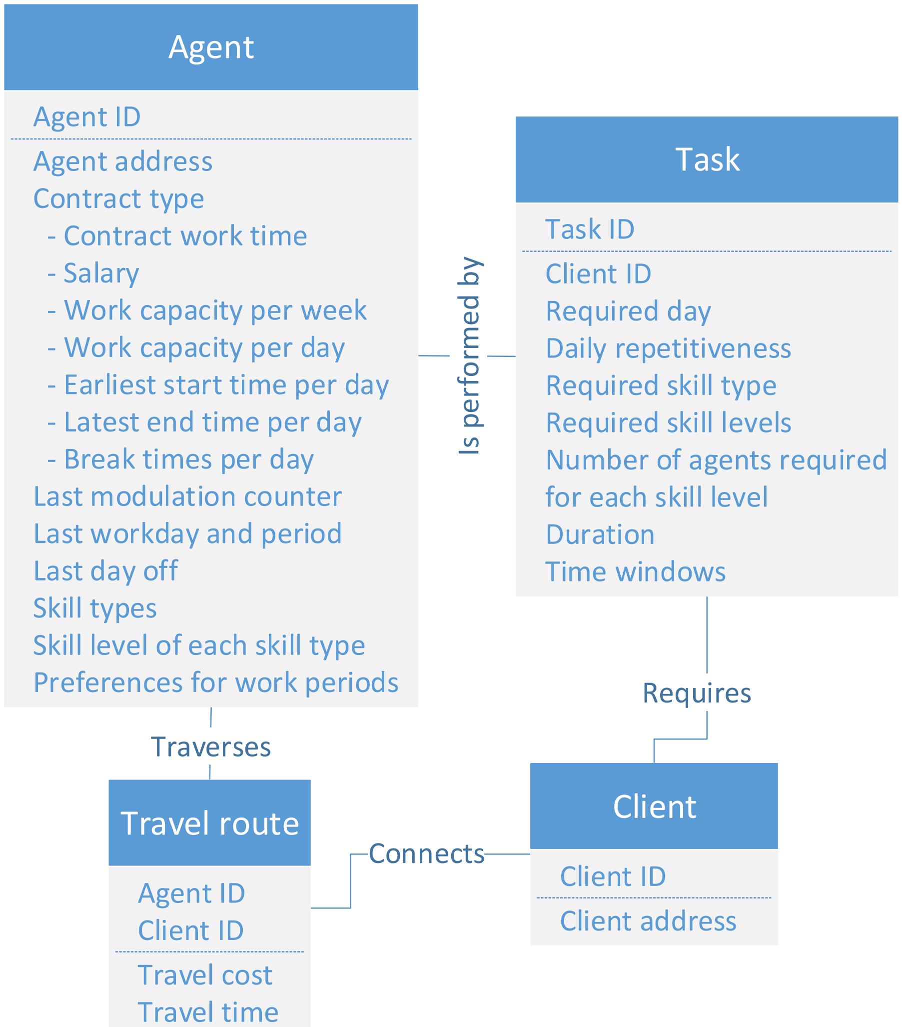

Figure 12. Class diagram for the problem in a context of variable demand

5.2.2.3. Agent

Contract type**:** Four of the six agent contract types that we consider here, including the 12x36, 5x2, 6x1, and 5x1 contracts, were already presented previously (see Table 11, Section 4.2.3). However, the characteristics in the last column of Table 11 are considered differently in this chapter (Table 16). The estimated travel time per week is considered instead of the number of work trips per week in Table 11. However, this new characteristic in Table 16 can be derived easily from that in Table 13. The estimated travel time per week equals the multiplication of the number of work trips per week and the estimated travel time per work trip (assumed to be 3 hours). The two new work contracts, which we consider as a lever to increase the workforce adaptation, are the shift full-time 8x24 and shift part-time 4x20 contracts. The characteristics of the shift full-time contract 8x24 are similar to those of the 12x36 contract, which has been already used by many companies. However, the work shift duration of an agent with this contract is only 8 hours that allow her/him to better combine with other contracts than the 12x36 contract whose work shift duration is 12 hours. Moreover, the cycle of 8 work hours and 24 break hours allows this agent to have different start periods on different workdays, for example, period 1 on day 1, period 3 on day 2, and period 5 on day 3, which increases his/her flexibility. The part-time shift contract 4x20 is the most flexible contract among the six contracts considered. The number of work periods per day of an agent with this contract can vary between 1 and 3 periods while the number of workdays per week can vary between 3 and 7 days (see Table 16). However, because an agent generally needs about 8h of sleep per day and some time to travel between their home and their workplace, we set a minimum break of 12 hours between two consecutive work shifts for the 4x20 agents. This minimum duration is 11 hours in Brazil[21] or France[22]. By introducing these new work contracts, we hope to increase the number of possible combinations between contracts that can then help increase workforce adaptation.

Table 16: Characteristics of the two new flexible work contracts

Contract type	Work time	Break time	Possible work time/ week	Possible daily start periods	Contract work time/ week	Estimated travel time/ week
8x24	8h/32h	24h/32h	40h or 48h	Any time	42h	15.75h
4x20	0, 4h, 8h or 12h / day	At least 12h between 2 work shifts	24h-32h	Any time	28h	10.5h

Together with the introduction of two new flexible work contracts, we want to increase the flexibility of the six contracts by allowing flexible break hours/days between consecutive sets of work shifts/days. These more flexible contracts will be considered only in the case of dependence with buffer zones. The description of the six contracts with the consideration of flexibility is presented below.

[21] https://www.replicon.com/regulation/brazil-labor-laws/
[22] https://www.service-public.fr/particuliers/vosdroits/F990

✓ **Contract 12x36**: Agents with this contract have a work cycle of 12 work hours and 36 break hours. Their work schedules can be made more flexible by allowing them to have between 36 and 48 hours break time between any two consecutive work shifts of 12 hours, instead of a fixed duration of 36h (Table 17, row 2). However, because the smallest work unit that we consider is 4 hours, these agents can take a flexible break of 36, 40, 44, or 48 hours only.

✓ **Contract 8x24**: Agents with this contract have a work cycle of 8 work hours and 24 break hours. Their work schedules can be made more flexible by allowing them to have between 24 and 32 break hours between any two consecutive work shifts of 8 hours, instead of a fixed duration of 24h (Table 17, row 3). Similarly, because the smallest work unit that we consider is 4 hours, these agents can take a flexible break of 24, 28, or 32 hours only.

✓ **Contract 4x20**: Because the daily and weekly work schedules of these agents are already very flexible, we do not consider other ways to increase their flexibility (Table 17, row 4).

✓ **Contract 5x2**: During a week, agents with this contract have 5 consecutive workdays and then 2 consecutive days off. Their work schedules can be made more flexible by allowing them to have 2, 3, or 4 days off between 2 consecutive sets of 5 workdays instead of a fixed number of 2 days off (Table 17, row 5).

✓ **Contract 6x1**: During a week, agents with this contract have 6 consecutive workdays and 1 day off. Their work schedules can be made more flexible by allowing them to have 1 or 2 days off between 2 consecutive sets of 6 workdays instead of 1 day off all the time (Table 17, row 6).

✓ **Contract 5x1:** Agents with this contract have 5 consecutive workdays and 1 day off for any period of 6 consecutive days. Their work schedules can be made more flexible by allowing them to have 1 or 2 days off between 2 consecutive sets of 5 workdays instead of only 1 day off all the time (Table 17, row 7).

Table 17. Work contracts' characteristics after increasing their flexibility

Contract type	Shift/ non shift	Possible number of work hours per day	Break hours (days) per 2 consecutive work shifts (days)	Possible number of work hours per week
1 (12x36)	Shift	0 or 12h	36, 40, 44 or 48h/ 2x12h	24, 28, 32, 36, 40, 44, or 48h
2 (8x24)	Shift	0 or 8h	24, 28, or 32h/2x8h	32, 36, 40, 44, or 48h
3 (4x20)	Shift	Same as in Table 16		
4 (5x2)	Non-shift	0 or 8h	2 to 4 days/2x5 days	24, 32, or 40h
5 (6x1)	Non-shift	0 or 8h	1 to 2 days /2x6 days	40h or 48h
6 (5x1)	Non-shift	0 or 8h	1 to 2 days/2x5 days	40h or 48h

To travel to client sites, each agent is estimated to spend a fixed amount of time per work trip. We chose three hours for this fixed duration based on the experimentation for local planning in Section 4.3.2. The average work-trip duration per agent for all the instances is about 3 hours. Moreover, the travel time is assumed the same from the agents' home to their workplace and the workplace back to their home. Because agents with different contract types have different numbers of work trips per week, their estimated travel time (Table 16, column 7) depends on their contract type. However, this value is used only to calculate agents' estimated work time, not their real work time.

In the service-to-business domain, because the task duration is generally long and working at the same workplace during a day can moreover, ensure a higher work efficiency for agents, we consider that an agent can only be assigned to a maximum of one task per day. This means that he/she cannot perform a task whose size is smaller than his/her daily work capacity (Table 18).

Table 18: Compatibility between tasks' duration and agents' work contract

Work contract /Task duration (h)	12 x 36	8 x 24	4 x 20	5 x 2	6 x 1	5 x 1
24	1	1	1	1	1	1
20	1	1	1	1	1	1
16	1	1	1	1	1	1
12	1	1	1	1	1	1
8	0	1	1	1	1	1
4	0	0	1	0	0	0

1: compatible, 0: incompatible

- Last modulation counter: see Section 2.2.3. Moreover, in the context of variable demand, not only the real work time but also the travel time between agents' homes and their workplaces are considered as an element of the total work time that is used to calculate agents' modulation counter.
- Last workday and period, and last day off: see Section 2.2.3
- Skill types, skill level of each skill type: see Section 4.2.3
- Preferences for work periods: see Section 2.2.3. Moreover, because shift agents (12x36, 8x24, and 4x20) can have different daily start and end times over the week, depending on the task they perform, they are assumed not to have a special preference for work periods. This value is, therefore, assumed to be zero for all of these agents. Non-shift agents, on the contrary, who depend on their daily routine, may prefer some work periods to others. Agents can be categorized into three groups by their preferences (see Table 19).

Table 19. Three groups of agents' preferences for different work periods

Period Agent group	1	2	3	4	5	6
1	0	+1	+1	0	-1	-1
2	-1	0	+1	+1	0	-1
3	0	-1	-1	0	+1	+1

+1: like, 0: neutral, -1: dislike

5.2.2.4. Travel route

See Section 4.2.4.

5.3. Problem modeling

As in chapter IV, we use the multi-objective MILP method to model and solve the problem, and the weighted sum method to deal with multi-objective optimization. The weight of each criterion in the multi-objective formulation can be variable and depends on the importance of each objective considered by the company. The presentation of our multi-objective MILP model consists of indices, parameters, variables, objectives, and constraints.

5.3.1. Indices

- Days of the planning horizon: {1,..,d,.. D} (D=7)
- Periods of a day: {1,..,t,..T} (T=6)
- Agents: {1,..i,..N}
- Clients: {1,..,p,.. P}
- Tasks: {1,..,j,.. J}
- Skill types: {1,..,k,..,K}
- Skill levels: {1,..,q,..,Q}

5.3.2. Parameters

- TCL_{jp} : Task j belongs to client p, =1 if yes, =0, otherwise, $\forall j = 1..J, \forall p = 1..P$
- TDA_j^d : Task j is required on day d, =1 if yes, =0, otherwise, $\forall j = 1..J, \forall p = 1..P$
- TD_j : Duration of task j, $\in\{1,2,..T\}$, $\forall j = 1..J$
- STW_j : Start time of task j, $\in\{1,2,..T\}$, $\forall j = 1..J$
- ETW_j : End time of task j, $\in\{1,2,..T\}$, $\forall j = 1..J$
- NBA_{jkq} : Number of agents having skill type k level q required by task j, $\in\{1,2,\ldots\}$ $\forall j = 1..J, \forall k = 1..K, \forall q = 1..Q$
- NB_j : Total number of agents required by task j, $NB_j = \sum_{k=1}^{K}\sum_{q=1}^{Q} NBA_{jkq}$, $\forall j = 1..J$
- SA_{ikq} : Agent i has skill type k level q, =1 if yes, =0 otherwise, $\forall i = 1..N, \forall k = 1..K, \forall q = 1..Q$
- CT_i : Contract type of agent i (see Table 16, column 1), $\in\{1,2,..6\}$, $\forall i = 1..N$
- $MWTD_i$: Daily work time of agent i if he is active on that day (in number of periods), $\in\{1,2,..T\}, \forall i = 1..N$

- WWT_i : Weekly contract work time of agent i (see Table 16, column 6), $\in\{1,2,..T\}$, $\forall i=1..N$
- WTT_i : Weekly estimated travel time of agent i (see Table 16, column 7), $\in\{1,2,\ldots\}$, $\forall i=1..N$
- CTA_{ij} : Compatibility between the duration of task j and the contract type of agent i, =1 if compatible, =0 otherwise, $\forall i=1..N, \forall j=1..J$ (Cf. Table 18)
- IC_i : Last modulation counter of agent i on the previous planning horizon, $\forall i=1..N$
- PR_i^t : Preference of agent i for period t, = -1: dislike, =0: neutral, =1: like, $\forall i=1..N, \forall t=1..T$
- LD_i : The last workday of agent i in the previous planning horizon, $LD_i \in\{1,2,..7\}\cup\{99)$, $LD_i=99$ if agent i did not work any day in the previous planning horizon
- LS_i : The last work period of the last workday of agent i in the previous planning horizon, $LS_i \in\{1,2,..6\}\cup\{99\}$, $LS_i=99$ if agent i did not work any day in the previous planning horizon
- LDO_i : The last day off in the previous planning horizon of agent i, $LDO_i \in\{1,2,...\}$, $LDO_i=99$ if agent i did not work any day in the previous planning horizon
- TC_{ip} : Travel cost from agent site i to client site p, $\forall j=1..J, \forall p=1..P$
- TT_{ip} : Travel time from agent site i to client site p, $\forall j=1..J, \forall p=1..P$
- ICP_{ip} : Incompatibility between agent i and client p, =1 if incompatible, =0, otherwise, i=1..N, p=1..P

5.3.3. Variables

- x_{ij}^t : =1 if agent i performs task j in period t, =0 otherwise, $\forall i=1..N, \forall j=1..J, \forall t=1..T$.

These variables are the main variables of the model that reflect the planning decisions. The other variables below are complementary variables that help to build the model but can be derived from the main variables.

- y_{ij} : =1 if agent i performs task j, =0 otherwise, $\forall i = 1..N, \forall j = 1..J$
- z_i^{dt} : =1 if agent i works in period t of day d, =0 otherwise, $\forall i = 1..N, \forall d = 1..D, \forall t = 1..T$
- w_i^d : =1 if agent i works on day d, =0 otherwise, $\forall i = 1..N, \forall d = 1..D$
- u_i : =1 if agent i works, =0, otherwise, $\forall i = 1..N$
- v_i : Real work time of agent i during the planning horizon, including travel time,

$\forall i = 1..N$

- mmc : Maximum absolute value of agents' modulation counters
- b_i^{dt} : =1 if agent i with a 12x36 contract works between periods t and t+2 of day d, =0

otherwise, $\forall i = 1..N, \forall d = 1..D, \forall t = 1..(T-2)$

- c_i^{dt} : =1 if agent i who has a work contract type 2/4/5/6 works between periods t and t+1

of day d, =0 otherwise, $\forall i = 1..N, \forall d = 1..D, \forall t = 1..(T-1)$

5.3.4. Objectives

In this model, we consider three objectives. The first objective is the minimization of the total travel costs between agents' homes and their workplaces (2). The second objective is the maximization of the workload balance between agents by minimizing the maximum absolute value of their modulation counters (3). The last objective is the maximization of agents' preference satisfaction for assigned work periods (4). These latter two objectives ensure agents' satisfaction that can help the company ensure its employees do not leave to go to the competitors. These three objectives are aggregated in a weighted sum objective function (1).

Minimize: $\alpha\Pi_{TC} + \beta\Pi_{MC} - \gamma\Pi_{PR}$ (1)

- $\Pi_{TC} = \sum_{i=1}^{N}\sum_{j=1}^{J}\sum_{p=1}^{P}(2 \times TC_{ip} \times TCL_{jp} \times y_{ij})$ (2)

- $\Pi_{MC} = mmc$ (3)

- $\Pi_{PR} = \sum_{i=1}^{N}\sum_{d=1}^{D}\sum_{t=1}^{T} PR_i^t \times z_i^{dt}$ (4)

5.3.5. Constraints

The constraints are divided into two groups that include the common constraints, which are shared by the three types of dependence between planning horizons, and the specific constraints of each of these three types.

5.3.5.1. Common constraints

- $\sum_{i=1}^{N} SA_{ikq} \times x_{ij}^t \geq NBA_{jkq}, \forall j = 1..J, \forall k = 1..K, \forall q = 1..Q, \forall t = STW_j..ETW_j$ (5)

- $\sum_{i=1}^{N} x_{ij}^t = NB_j, \forall j = 1..J, \forall t = STW_j..ETW_j$ (6)

- $x_{ij}^t = 0, \forall i = 1..N, \forall j = 1..J, \forall t = 1..T / t < STW_j \text{ or } t > ETW_j$ (7)

Constraints (5) and (6) ensure that for each skill type and skill level, the number of agents assigned to a task in each period within its time windows $[STW_j, ETW_j]$ has to equal the number of agents required. Constraints (5) use inequalities instead of equalities because some agents may have a skill level for some skill types that are not exploited by the task (multi-skilled agents). These inequalities still allow the number of agents of each skill type and skill level assigned to a task to be greater than the number that it actually requires. Constraints (6) are added to ensure that these numbers are equal globally. Constraints (7) make sure that no agent is assigned to a task at any period outside of its time windows.

- $y_{ij} \leq CTA_{ij}, \forall i = 1..N, \forall j = 1..J$ (8)

- $\sum_{j=1}^{J} TDA_j^d \times y_{ij} = w_i^d, \forall i = 1..N, \forall d = 1..D$ (9)

Constraints (8) ensure the compatibility between a task duration and an agent contract type (see Table 18). An agent can only be assigned to a task whose duration is greater than or equal to his/her daily work capacity. Constraints (9) ensure that each agent is assigned to a maximum of one task per day.

- $$\sum_{t=1}^{T} x_{ij}^{t} = MWTD_i \times y_{ij}, \forall i = 1..N / CT_i \in \{1,2,4,5,6\}, \forall j = 1..J \qquad (10)$$
- $$y_{ij} \le \sum_{t=1}^{T} x_{ij}^{t} \le 3 \times y_{ij}, \forall i = 1..N / CT_i = 3, \forall j = 1..J \qquad (11)$$
- $$\sum_{j=1}^{J} TDA_j^d \times x_{ij}^t = z_i^{dt}, \forall i = 1..N, \forall d = 1..D, \forall t = 1..T \qquad (12)$$
- $$\sum_{t=1}^{T} z_i^{dt} = MWTD_i \times w_i^d, \forall i = 1..N / CT_i \in \{1,2,4,5,6\}, \forall d = 1..D \qquad (13)$$
- $$w_i^d \le \sum_{t=1}^{T} z_i^{dt} \le 3 \times w_i^d, \forall i = 1..N / CT_i = 3, \forall d = 1..D \qquad (14)$$
- $$u_i \le \sum_{d=1}^{D} w_i^d \le D \times u_i, \forall i = 1..N \qquad (15)$$

Constraints (10)-(15) show the relations between the problem variables. Because an agent (with a contract type different from 4x20) is assumed to perform a maximum of one task per day, constraints (10) are used to ensure that if this agent performs a task, he/she has to work with his/her daily capacity $MWTD_i$. Constraints (11) imply that an agent with contract 4x20 can perform a task with at most his/her maximum daily capacity of 3 periods (12h). However, he/she can perform a task whose size is larger than 12 hours by working together with another agent. Constraints (12) ensure that an agent works in a particular period of a day if he/she performs a task in that period of that day. Constraints (13) imply that if an agent (with a contract type different from 4x20) works on a day, he/she has to work at his/her daily capacity $MWTD_i$. Constraints (14) ensure that an agent with contract 4x20 cannot exceed his/her maximum daily capacity of 3 periods (12h). Constraints (15) make sure that an agent works during the planning horizon if he/she works on at least one of its days.

- $$\sum_{t=1}^{T-2} b_i^{dt} \le 1,\ \forall i / CT_i = 1, \forall d = 1..D \quad (16)$$

- $$\begin{cases} z_i^{dt} = b_i^{d(t-2)} + b_i^{d(t-1)} + b_i^{dt}, \forall t = 3..4 \\ z_i^{d5} = b_i^{d3} + b_i^{d4} \\ z_i^{d6} = b_i^{d4} \\ z_i^{d2} = b_i^{d1} + b_i^{d2} \\ z_i^{d1} = b_i^{d1} \end{cases}, \forall i / CT_i = 1,\ \forall d = 1..D, \quad (17)$$

- $$\sum_{t=1}^{T-1} c_i^{dt} \le 1,\ \forall i / CT_i \in \{2,4,5,6\},\ \forall d = 1..D \quad (18)$$

- $$\begin{cases} z_i^{dt} = c_i^{d(t-1)} + c_i^{dt}, \forall t = 2..5 \\ z_i^{d1} = c_i^{d1} \\ z_i^{d6} = c_i^{d5} \end{cases}, \forall i / CT_i \in \{2,4,5,6\},\ \forall d = 1..D \quad (19)$$

- $$\begin{cases} z_i^{d1} + z_i^{dt} \le u_i, \forall t = 4..6 \\ z_i^{d2} + z_i^{dt} \le u_i, \forall t = 5..6 \\ z_i^{d3} + z_i^{d6} \le u_i \end{cases}, \forall i / CT_i = 3,\ \forall d = 1..D \quad (20)$$

- $$z_i^{dt} + z_i^{d(t+2)} - z_i^{d(t+1)} \le u_i, \forall t = 1..4, \forall i / CT_i = 3,\ \forall d = 1..D \quad (21)$$

Constraints (16) and (17) ensure the continuity of the work periods of the agents with shift contract 12x36. An agent of this contract type can perform tasks only between periods 1 and 3, 2 and 4, 3 and 5, or 4 and 6. Similarly, constraints (18) and (19) ensure the continuity of the work periods of the agents with shift contract 8x24 and non-shift contracts; an agent with this contract type can perform tasks only between periods 1 and 2, 2 and 3, 3 and 4, 4 and 5, or 5 and 6. Constraints (20) and (21) ensure the continuity of the work periods of the agents with shift contract 4x20; if an agent with this contract works 2 or 3 periods on a day, these periods have to be consecutive.

- $$\begin{cases} z_i^{dt} - z_i^{d_1 t} \le 2 - (w_i^d + w_i^{d_1}) \\ z_i^{dt} - z_i^{d_1 t} \ge w_i^d + w_i^{d_1} - 2 \end{cases}, \forall d = 1..D, \forall d_1 = (d+1)..D, \forall i / CT_i \in \{4,5,6\} \quad (22)$$

Constraints (22) ensure that if a non-shift agent (contract types 4, 5 or 6) works in a particular period of a day, he/she has to work in the same period on the other days of the week (except for his/her days off).

- $$v_i = 4 \times \sum_{d=1}^{D}\sum_{t=1}^{T} z_i^{dt} + 2 \times \sum_{j=1}^{J}\sum_{p=1}^{P} TT_{ip} \times TCL_{jp} \times y_{ij}, \forall i = 1..N \qquad (23)$$
- $$mmc \geq v_i - (WWT_i + WTT_i) \times u_i + IC_i, \forall i = 1..N \qquad (24a)$$
- $$mmc \geq -[v_i - (WWT_i + WTT_i) \times u_i + IC_i], \forall i = 1..N \qquad (24b)$$

Constraints (23) refer to the total real work time of an agent during the planning horizon, including travel time. Constraints (24a) and (24b) define the maximum absolute value of the agents' modulation counters.

5.3.5.2. Specific constraints of three types of dependence

We consider one by one the specific constraints of three ways to model the dependence between planning horizons, including the independent, the "fully" dependent, and our proposition - the dependent with buffer zones. The independent and the "fully" dependent cases are mainly for comparison with our proposition, the dependent with buffer zones.

Independent

- $$z_i^{dt} = z_i^{(d+2)t}, \forall i = 1..N / CT_i = 1, \forall d = 1..(D-2), \forall t = 1..T \qquad (25A)$$
- $$\sum_{d_1=d}^{d+1}\sum_{t=1}^{T} z_i^{d_1 t} = 3 \times u_i, \forall i = 1..N / CT_i = 1, \forall d = 1..(D-1) \qquad (26A)$$
- $$z_i^{dt} = z_i^{(d+1)(t+2)}, \forall i = 1..N / CT_i = 2, \forall d = 1..(D-1), \forall t = 1..(T-2) \qquad (27A)$$
- $$z_i^{dt} = z_i^{(d+2)(t-T+2)}, \forall i = 1..N / CT_i = 2, \forall d = 1..(D-2), \forall t = (T-1)..T \qquad (28A)$$
- $$\sum_{d_1=d}^{d+3}\sum_{t=1}^{T} z_i^{d_1 t} = 6 \times u_i, \forall i = 1..N / CT_i = 2, \forall d = 1..(D-3) \qquad (29A)$$

Constraints (25A) and (26A) are applied to agents with contract 12x36. Constraints (25A) imply that if an agent works in period t, on day d, he/she also has to work in the same period 2 days later. Constraints (26A) ensure that if an agent of this contract type is used, he/she has to work exactly 3 periods of 4 hours for any 2 consecutive days. Similarly, constraints (27A), (28A), and (29A) are applied to agents with contract 8x24. Constraints (27A) imply that if an agent works in period t (t≤T-2), on day d, he/she also has to work in period t+2, 1 day later. Constraints (28A) ensure that if an agent works in periods T-1 or T, on day d, he/she also has to work in period 1 or 2, 2 days later. Constraints (29A) ensure that if an agent of this contract type is used, he/she has to work 6 periods of 4 hours for any 4 consecutive days.

- $$6 \times u_i \le \sum_{d=1}^{D}\sum_{t=1}^{T} z_i^{dt} \le 8 \times u_i, \forall i = 1..N / CT_i = 3 \qquad (30A)$$

- $$\sum_{t_1=t}^{T} z_i^{dt_1} + \sum_{t_2=1}^{t-T+3} z_i^{(d+1)t_2} \le 1, \forall i = 1..N / CT_i = 3, \forall d = 1..(D-1), \forall t = (T-2)..T \qquad (31A)$$

Constraints (30A) and (31A) are applied to agents with contract 4x20. Constraints (30A) imply that each agent with contract 4x20 has to work between 6 and 8 periods of 4 hours per week. Constraints (31A) ensure the minimum time lag between two consecutive work periods (no more than one work period for any duration of 16 hours).

- $$\begin{cases} w_i^2 + w_i^7 = u_i \\ w_i^1 + w_i^6 = u_i \\ w_i^1 + w_i^7 \le u_i \\ w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (32A)$$

- $$\begin{cases} w_i^1 + w_i^7 = u_i \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = w_i^6 = u_i \end{cases}, \forall i = 1..N / CT_i = 5 \qquad (33A)$$

- $$\begin{cases} w_i^1 + w_i^6 = u_i \\ w_i^1 = w_i^7 \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (34A)$$

Agents with contract 5x2 have to work 5 consecutive days during the week that can be from day 1 to day 5, day 2 to day 6, or day 3 to day 7. In any of these three cases, these agents have to work on days 3, 4, and 5 (the last equations of constraints (32A)). The other two days can be chosen between days 1 and 2, days 2 and 6, or days 6 and 7 (the first three equations of constraints (32A)).

Agents with contract 6x1 have to work 6 consecutive days during the week that can be from day 1 to day 6, or day 2 to day 7. In any of these two cases, these agents have to work from day 2 to day 6. The other day can be chosen between day 1 and day 7 (33A). Agents with contract 5x1 have to work 5 consecutive days and have a break of 1 day for any duration of 6 days. Five consecutive days can be from day 1 to day 5, or day 2 to day 6. So, they can work 6 days during the week, taking day 6 off, or 5 days from day 2 to day 6, taking both days 1 and 7 off. In any of these two cases, these agents have to work on days 2, 3, 4, and 5 (the last equations of constraints (34A)). The other workdays can be day 6 or days 1 and 7 (the first two equations of constraints (34A))

“Fully” dependent

The “fully” dependent case considers that the availability of an agent in the current planning horizon completely depends on what he/she did in the previous horizon. This type of dependence is very realistic but too constrained and we can end up with a situation that no solution meets all the constraints. This way to model the dependence between the planning horizons is, therefore, not the core of our study but will only be used for comparison. The constraints considered are presented in Appendix D.

Dependent with buffer zones

For our proposition, dependent with buffer zones, we use three new parameters LD_i, LS_i, and LDO_i respectively corresponding to the last workday, last period, and last day off of the agent in the previous horizon. These three parameters are used to model the links between agents’ last activity on the previous horizon and their first activity on this horizon.

Contract 12x36

Table 20. Relations between the last workday and period on the previous horizon and the possible earliest workday and period on this horizon for agents with contract 12x36

LD_i / LS_i	3	4	5	6
6	Period 1 day 1	Period 2 day 1	Period 3 day 1	Period 4 day 1
7	Period 1 day 2	Period 2 day 2	Period 3 day 2	Period 4 day 2

If $LD_i = 99$: Constraints (25C)-(33C) are applied. Constraints (25C)-(29C) ensure that the periods between two consecutive shifts of 3 work periods are break time (non-work time). Constraints

(30C) and (31C) ensure that an agent with 12x36 contract works at most 1 shift of 12 hours for any duration of 48h. Constraints (32C) and (33C) ensure that an agent with this contract works at least 1 shift of 12 hours for any duration of 60h.

- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=t_1+3}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=2..3,\forall d_1=1..5,\forall t_2=t_1..4 \qquad (25C)$$
- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=t_1+3}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=1,\forall d_1=1..5,\forall t_2=2..4 \qquad (26C)$$
- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=t_1+3}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=1,\forall d_1=1..5,\forall t_2=1 \qquad (27C)$$
- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=4,\forall d_1=1..5,\forall t_2=4 \qquad (28C)$$
- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+3)t_2})\geq\sum_{t=1}^{T}(z_i^{(d_1+1)t}+z_i^{(d_1+2)t}),$$
  $$\forall i=1..N/CT_i=1,\forall t_1=4,\forall d_1=1..4,\forall t_2=1 \qquad (29C)$$
- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_1=1}^{T}z_i^{(d+1)t_1}+\sum_{t_1=1}^{t-1}z_i^{(d+2)t_1}\leq u_i,\ \forall i=1..N/CT_i=1,\forall t=2..T,\forall d=1..5 \qquad (30C)$$
- $$\sum_{t_1=1}^{T}z_i^{dt_1}+\sum_{t_1=1}^{T}z_i^{(d+1)t_1}\leq u_i,\ \forall i=1..N/CT_i=1,\forall t=1,\forall d=1..6 \qquad (31C)$$
- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_1=1}^{T}z_i^{(d+1)t_1}+\sum_{t_1=1}^{t+2}z_i^{(d+2)t_1}\geq u_i,\ \forall i=1..N/CT_i=1,\forall t=1..4,\forall d=1..5 \qquad (32C)$$

- $$\sum_{t_1=t}^{T} z_i^{dt_1} + \sum_{t_1=1}^{T} z_i^{(d+1)t_1} + \sum_{t_1=1}^{T} z_i^{(d+2)t_1} + \sum_{t_1=1}^{t-4} z_i^{(d+3)t_1} \geq u_i \,, \forall i = 1..N / CT_i = 1, \forall t = 5..6, \forall d = 1..4$$

(33C)

If LD_i = 6/7 and LS_i = 3/4/5/6: Besides constraints (25C)-(33C), we have moreover additional constraints (34C) and (35C). These constraints ensure the break time at the beginning of the current horizon for the agents who work at the end of the previous horizon.

- $z_i^{dt} = 0 \,,\ \forall i = 1..N / CT_i = 1, \forall d = 1..D / d = LD_i - 6, \forall t = 1..T$ (34C)

- $z_i^{dt} = 0 \,,\ \forall i = 1..N / CT_i = 1, \forall d = 1..D / d = LD_i - 5, \forall t = 1..T / t \leq LS_i - 3$ (35C)

Contract 8x24

Table 21. Relations between the last workday and period on the previous horizon and the possible earliest workday and period on this horizon for agents with contract 8x24

LD_i / LS_i	2	3	4	5	6
6	-	-	-	-	Period 1 day 1
7	Period 3 day 1	Period 4 day 1	Period 5 day 1	Period 6 day 1	Period 1 day 2

If LD_i = 6 or LD_i = 99: Constraints (36C)-(44C) are applied. Constraints (36C)-(40C) ensure that periods between two consecutive shifts of 2 work periods are break time (non-work time). Constraints (41C) and (42C) ensure that an agent with 8x24 contract works at most 1 shift of 8 hours for any duration of 32h. Similarly, constraints (43C) and (44C) ensure that an agent with an 8x24 contract works at least 1 shift of 8 hours for any duration of 40h.

- $$8 \times (2 - c_i^{d_1 t_1} - c_i^{(d_1+1)t_2}) \geq \sum_{t=t_1+2}^{T} z_i^{d_1 t} + \sum_{t=1}^{t_2-1} z_i^{(d_1+1)t} \,,$$

$$\forall i = 1..N / CT_i = 2, \forall t_1 = 1..3, \forall t_2 = (2 + t_1)..5, \forall d_1 = 1..6$$ (36C)

- $$8 \times (2 - c_i^{d_1 t_1} - c_i^{(d_1+2)t_2}) \geq \sum_{t=t_1+2}^{T} z_i^{d_1 t} + \sum_{t=1}^{T} z_i^{(d_1+1)t} + \sum_{t=1}^{t_2-1} z_i^{(d_1+2)t} \,,$$

$$\forall i = 1..N / CT_i = 2, \forall t_1 = 4, \forall t_2 = 2..(t_1 - 2), \forall d_1 = 1..5$$ (37C)

- $$8\times(2-c_i^{d_1t_1}-c_i^{(d_1+2)t_2})\ge\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$

  $$\forall i=1..N/CT_i=2,\forall t_1=5,\forall t_2=2..(t_1-2),\forall d_1=1..5 \qquad (38C)$$

  $$8\times(2-c_i^{d_1t_1}-c_i^{(d_1+2)t_2})\ge\sum_{t=t_1+2}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t},$$

  $$\forall i=1..N/CT_i=2,\forall t_1=3..4,\forall t_2=1,\forall d_1=1..5 \qquad (39C)$$

- $$8\times(2-c_i^{d_1t_1}-c_i^{(d_1+2)t_2})\ge\sum_{t=1}^{T}z_i^{(d_1+1)t},\ \forall i=1..N/CT_i=2,\forall t_1=5,\forall t_2=1,\forall d_1=1..5 \qquad (40C)$$

- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_2=1}^{1+t}z_i^{(d+1)t_2}\le 2\times u_i,\ \forall i=1..N/CT_i=2,\forall t=1..5,\forall d=1..6 \qquad (41C)$$

- $$z_i^{d6}+\sum_{t=1}^{T}z_i^{(d+1)t}+z_i^{(d+2)1}\le 2\times u_i,\ \forall i=1..N/CT_i=2,\forall d=1..5 \qquad (42C)$$

- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_2=1}^{3+t}z_i^{(d+1)t_2}\ge 2\times u_i,\ \forall i=1..N/CT_i=2,\forall t=1..3,\forall d=1..6 \qquad (43C)$$

- $$\sum_{t_1=t+3}^{T}z_i^{dt_1}+\sum_{t_2=1}^{T}z_i^{(d+1)t_2}+\sum_{t_3=1}^{t}z_i^{(d+1)t_3}\ge 2\times u_i,\ \forall i=1..N/CT_i=2,\forall t=1..3,\forall d=1..5 \qquad (44C)$$

If LD_i = 7 and LS_i = 2/3/4/5/6: Beside constraints (36C)-(44C), we have moreover additional constraints (45C). Constraints (45C) imply that no agent with an 8x24 contract can perform tasks before the end of their break time at the end of the previous planning horizon and at the beginning of this planning horizon.

- $$z_i^{1t}=0,\ \forall i=1..N/CT_i=1,\forall t\le LS_i \qquad (45C)$$

Contract 4x20

Constraints (30A) and (31A) are also applied to the case of dependent with buffer zones. Additional constraints are as follows:

If $LD_i \neq 7$ or $LD_i = 7$ and $LS_i \leq 3$: no additional constraints needed

If LD_i =7 and $LS_i \geq 4$: we have additional constraints (46C). These constraints ensure the minimum time lag between the last work period of day 7 in the previous planning horizon and the first work period of day 1 in the current planning horizon.

- $$\sum_{t=1}^{LS_i-T+3} z_i^{1t} = 0, \forall i = 1..N / CT_i = 3 \qquad (46C)$$

Contract 5x2

Because the number of days off between two consecutive sets of five workdays can vary between two and four, knowing only the last day off of an agent in the previous planning horizon is not enough to determine their days off in this planning horizon. When the last day-off is day 7, the other days off can be day 6, day 1, days 6 and 5, or days 6, 5, and 4. We use four values of LDO_i (7, 8, 9, and 10) to represent these four possibilities.

Table 22. Relations between the last days off on the previous horizon and days off on this horizon for agents with contract 5x2

LDO_i	2	3	4	5	6	7	8	9	10
Days off on the previous horizon	1 and 2	2 and 3	3 and 4	4 and 5	5 and 6	6 and 7	1 and 7	5, 6, and 7	4, 5, 6, and 7
Days off on the current horizon	1-2, 1-3 or 1-4	2-3, 2-4 or 2-5	3-4, 3-5 or 3-6	4-5, 4-6 or 4-7	5-6 or 5-7	6-7, 1&7 or 1-2	1-2, 1&7, or 1-3	6 -7 or 1&7	6 and 7

If LDO_i = 99 or LDO_i = 7: Constraints (32A) are applied.

If $2 \leq LDO_i \leq 6$: Constraints (47C) are applied

- $$\begin{cases} w_i^{LDO_i-1} + w_i^{LDO_i} = 0 \\ w_i^d = u_i, \forall d = 1..D / d \leq LDO_i - 2 \text{ or } d \geq LDO_i + 3, \ \forall i = 1..N / CT_i = 4 \\ w_i^{LDO_i+1} \leq w_i^{LDO_i+2} \end{cases} \qquad (47C)$$

If LDO_i = 8: Constraints (48C) are applied

- $$\begin{cases} w_i^4 = w_i^5 = w_i^6 = u_i \\ w_i^1 = 0 \\ w_i^2 + w_i^7 = u_i \\ w_i^2 \le w_i^3 \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (48C)$$

If $LDO_i = 9$: Constraints (49C) are applied

- $$\begin{cases} w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \\ w_i^7 = 0 \\ w_i^1 + w_i^6 = u_i \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (49C)$$

If $LDO_i = 10$: Constraints (50C) are applied

- $$\begin{cases} w_i^1 = w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \\ w_i^6 = w_i^7 = 0 \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (50C)$$

Constraints (47C)-(50C) allows a break time from 2 to 4 days between any 2 consecutive sets of 5 workdays (see Table 22.

Contract 6x1

Table 23. Relations between the last days off on the previous planning horizon and days off on this horizon for agents with contract 6x1

LDO_i	1	2	3	4	5	6	7	8
Days off on the previous horizon	1	2 or 1 and 2	3 or 2 and 3	4 or 3 and 4	5 or 4 and 5	6 or 5 and 6	6 and 7	7 only
Days off on the current horizon	1 or 1 and 2	2 or 2 and 3	3 or 3 and 4	4 or 4 and 5	5 or 5 and 6	6 or 6 and 7	7	1 or 7

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$ or $LDO_i = 8$: Constraints (33A) are applied.

If $1 \le LDO_i \le 6$: constraints (51C) are applied

- $$\begin{cases} w_i^{LDO_i} = 0 \\ w_i^d = u_i,\ d = 1..D / d \le LDO_i - 1 \text{ or } d \ge LDO_i + 2 \end{cases}, \forall i = 1..N / CT_i = 5 \qquad (51C)$$

If $LDO_i = 7$: constraints (52C) are applied

- $$\begin{cases} w_i^7 = 0 \\ w_i^d = u_i, \forall d = 1..(D-1) \end{cases}, \forall i = 1..N / CT_i = 5 \qquad (52C)$$

Constraints (51C) and (52C) allows a break time from 1 to 2 days between any 2 consecutive sets of 6 workdays (see Table 23).

Contract 5x1

Table 24. Relations between the last day off in the previous horizon and days off on this horizon for agents with contract 5x1

LDO_i	2	3	4	5	6	7	8
Days off on the previous horizon	2 or 1 and 2	3 or 2 and 3	4 or 3 and 4	5 or 4 and 5	6 or 5 and 6	6 and 7	7 only
Days off on the current horizon	1 and 7 or 1 and 2	2 or 2 and 3	3 or 3 and 4	4 or 4 and 5	5 or 5 and 6	6 or 6 and 7	6 or 6 and 7 or 1 and 7

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$: Constraints (34A) are applied.

If $3 \le LDO_i \le 7$: Constraints (53C) are applied.

- $$\begin{cases} w_i^{LDO_i - 1} = 0 \\ w_i^d = u_i,\ d = 1..D / d \le LDO_i - 2 \text{ or } d \ge LDO_i + 1 \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (53C)$$

If $LDO_i=2$: Constraints (54C) are applied.

- $$\begin{cases} w_i^1 = 0 \\ w_i^2 + w_i^7 = u_i \\ w_i^3 = w_i^4 = w_i^5 = w_i^6 = u_i \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (54C)$$

If $LDO_i=8$: Constraints (55C) are applied.

- $$\begin{cases} w_i^1 + w_i^6 = u_i \\ w_i^1 \ge w_i^7 \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (55C)$$

Constraints (53C)-(55C) allow a break time from 1 to 2 days between any two consecutive sets of five workdays (Table 24).

5.4. Data and methodology for the experimentation

In this section, we present the data benchmark, which is used to generate the instances for experiments (Section 5.4.1), and the experiment methodology (Section 5.4.2).

5.4.1. Data

We use the original data benchmark provided by our Brazilian partner (see Section 4.3.2.1), which has 672 agents and 141 tasks, to generate a new data benchmark for the experiments of this chapter. However, the data needed for our experiments are not the same as those used in chapter IV. The tasks used for chapter IV are weekly tasks characterized by task coverage types while those used for this chapter are daily tasks characterized by duration, time windows, and required day. The total numbers of agents are the same in the two chapters. However, this chapter considers five additional agent characteristics that include the last modulation counter, the preferences for work periods, the last workday and period, and the last day off. Therefore, to create data instances for this chapter, we need to generate daily tasks from existing weekly tasks and the data for the five new agent characteristics.

In the original benchmark, we have 141 tasks belonging to 12 task coverage types (numbered from 1 to 12) (Table 10, page 64). To generate new daily tasks, we keep the same daily task duration, its start and end times as those of the original benchmark; we change only its daily repetitiveness over the week. For example, a weekly task with coverage type 1, required for 5 consecutive days per week, is split into 5 daily tasks of 5 consecutive days, possibly from day 1 to day 5, day 2 to day 6 or day 3 to day 7; the probabilities that these three cases are generated are assumed to be the same. By doing the same for the other task coverage types, we generated 1343 daily tasks from 141 weekly tasks.

For the agent data, agents' last modulation counters are generated by a normal distribution. The agents' preferences for certain work periods are generated differently for shift and non-shift agents. Shift agents (12x36, 8x24, and 4x20) are assumed not to have a special preference for any work periods. By contrast, non-shift agents, who depend on their daily routine, may prefer some work periods to others. Regarding the last workday and period, and the last day off, we assumed that the agent work plan in the previous horizon is the company's manual plan. For further details on this data generation process, see Appendix. C.

The new benchmark, which is used to generate instances for our experiments, has 672 agents and 1,343 tasks belonging to 66 clients. The numbers of clients, tasks, and agents of each instance are chosen between 3 and 6, 60 and 100, and 30 and 60 respectively. The number of clients between 3 and 6 is a typical number of clients of a district and the numbers of tasks or agents chosen are common for these numbers of clients in the benchmark. Besides, the proportion of the number of extra agents in comparison to the number of agents required by tasks is set to be 15%; the proportion of shift agents is chosen between 25% and 75% and the remaining is non-shift agents. The size of the instances generated in this way is consistent with the problems encountered by our Brazilian partner.

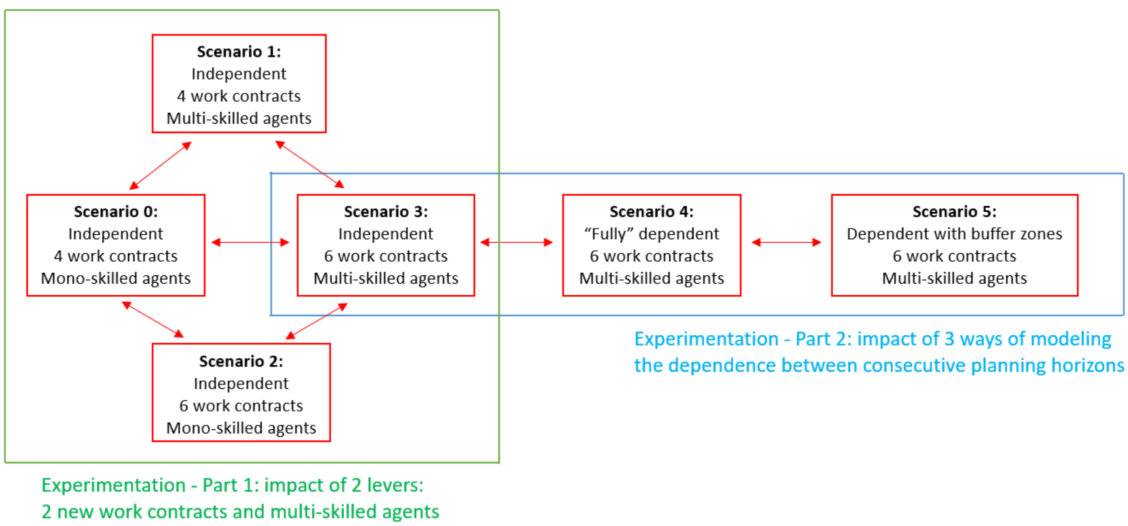

Figure 13. Six experiment scenarios

We consider six different scenarios in this experiment. The original scenario (scenario 0) corresponds to the current situation of the company where the agents are mono-skilled and only four work contracts are actually used. Scenario 1 also considers four work contracts but agents are multi-skilled. Scenario 2 considers only mono-skilled agents but with two new work contracts (8x24 and 4x20). Scenario 3 considers both multi-skilled agents and two new work contracts. Scenario 4 and 5 also consider both multi-skilled agents and two new work contracts as scenario 3 but in two other contexts. Scenario 4 considers the "fully" dependent case while scenario 5 studies the problem in the case of dependence with buffer zones (Figure 13).

We first generate 30 original instances for the experiments of scenario 0. To create an instance for scenario 1, which considers multi-skilled agents, from an original instance (scenario 0), we allow all the agents to work in other workplace types in addition to their main workplace. However, an agent can only work at another workplace type if this workplace is less complex than his current main workplace. For example, an agent working in a hospital can also work in a shop or a factory but the reverse is not allowed. In order to generate an instance for scenario 2, which considers two new work contracts, from an original instance, we fix the numbers of agents with non-shift contracts (5x2, 6x1, and 5x1). Among the 12x36 agents, we keep a third of them, replace a third by the 4x20 agents, and a remaining third by the 8x24 agents. Because the average work capacity of the 12x36 agent is 42 hours/week while that of the 4x20 agent is 28 hours/week, we replace every two 12x36 agents by three 4x20 agents to ensure the total work capacity. The replacement ratio between the 12x36 and 8x24 contracts is 1:1 because these agents have the same average work capacity. To generate an instance for scenario 3, which considers both multi-skilled agents and two new work contracts, from an original instance, we do both the steps above. Finally, the instances used for scenarios 4 and 5 are the same as those of scenario 3, only some constraints of the MILP model are different between these three scenarios (see Section 5.3.5.2).

Table 25 shows the characteristics of the 30 final instances used for our experiments. Among the six scenarios considered, we present the characteristics of the 30 final instances of scenario 3, which corresponds to the consideration of the six work contracts.

Table 25. Characteristics of the 30 instances used for experiments (scenario 3)

Indicator /Characteristic	Average	Min	Max
Number of clients	4.5	3	6
Number of tasks	84.2	71	95
Number of agents	47.2	37	60
Number of agents 12x36	7.6	4	12
Number of agents 8x24	7.3	4	12
Number of agents 4x20	11.3	5	19
Number of agents 5x2	6.6	0	14
Number of agents 6x1	12.5	7	19
Number of agents 5x1	1.9	0	6
Shift / non-shift rates	57%:43%	33%:67%	73%:27%

5.4.2. Methodology

We perform experiments for six scenarios. For each scenario, we solve four different problems. The first three are mono-objective problems with TC (agents' travel costs), MC (maximum absolute value of agents' modulation counters), and PR (agents' preferences for certain work periods) respectively. The fourth problem uses a weighted sum of TC, MC, and PR as the objective formulation. The associated coefficients α (of TC), β (of MC), and γ (of PR) are chosen to be the inverses of the three optimal objective values TC*, MC* and PR* obtained previously. This multi-objective formulation gives an equal contribution of each criterion to the global objective.

We use the CPLEX Studio IDE of IBM[23] embedded in Eclipse[24], installed on a powerful computer (Intel Xeon CPU E5-1620 V3, 2 x 3.5 GHz, 64G of RAM), to solve the problems. The CPU has eight processors working in parallel and each experiment is performed by only one processor. The maximum calculation time for each experiment is 10 hours and the relative MIP gap tolerance[25] is 1%.

The aim of the experiments is to evaluate the impact of the two proposed levers (the introduction of two new work contracts and the use of multi-skilled agents), and the three ways to model the dependence between planning horizons (independent, fully dependent, and dependent with buffer zones) on the feasibility and complexity of problem solving and the quality of the solutions obtained. The experiments are divided into two parts. In the first part (Section 5.5), we fix the dependence between planning horizons to be independent and investigate the combinations of the two levers (scenarios 0-3, Figure 13). As mentioned in Section 5.2.1, the independent case is not quite realistic when it assumes that all the resources used for planning (agents, vehicles, materials, etc.) are available since the beginning of the planning horizon. However, because this assumption helps simplify the problem a lot and is commonly used for academic research, to investigate the impact of the two levers on the problem, we choose to start with this simplification assumption. In the second part, we choose the combination of the two levers that gives the solutions

[23] https://www.ibm.com/fr-fr/products/ilog-cplex-optimization-studio
[24] https://www.eclipse.org/
[25] https://www.ibm.com/support/knowledgecenter/SSSA5P_12.7.1/ilog.odms.cplex.help/CPLEX/Parameters/topics/EpGap.html

with the best compromise between the three criteria considered and investigate how the three ways to model the dependence between planning horizons affect the problem (scenarios 3-5, Figure 13).

For each scenario, we solve three mono-objective and one multi-objective problems for the 30 instances considered. Three indicators are considered, including the calculation time (if the problem is solved optimally), the GAP value (if the problem is not solved optimally but a feasible solution is obtained), and the values of the three criteria considered. The calculation times and the GAP values are used to evaluate the complexity of problem solving while the values of the three criteria are used to evaluate the quality of solutions obtained in each scenario.

5.5. Organizational levers: new work contracts and multi-skilled agents

In this part of the experiments, we aim at first investigating how each of these two levers and their combinations (scenarios 0-3) affect the complexity of the three mono-objective and the multi-objective problems. Then, we evaluate their impact in terms of the quality of the solutions obtained. For each of the three mono-objective problems (with TC, MC, and PR respectively), we compare the value of the criterion (TC, MC, or PR respectively) between the scenarios. For the multi-objective problem, we evaluate the compromise of these three criteria between the scenarios.

5.5.1. Complexity of problem solving

The complexity of problem solving is considered through the GAP values of the solutions obtained for the 30 instances (Table 26 and Table 27) and the calculation time needed to solve the problem using Cplex (Table 28).

The results (Table 26 and Table 27) show that our resolution method is very efficient in solving the four problems in the first two scenarios, 4 work contracts, and mono-skilled agents and 4 work contracts and multi-skilled agents, where all 30 instances are solved optimally. For the last two scenarios, 6 work contracts and mono-skilled agents and 6 work contracts and multi-skilled agents, the resolution method is very efficient for the two mono-objective problems with MC or PR where all 30 instances are solved optimally. It is also quite efficient for the mono-objective problem with TC and the multi-objective problem, where most of the solutions obtained within 10 hours are near-optimal (the GAP value is between 1% and 5%). Moreover, the average GAP values for the 30 instances are only between 3% and 3.7% for these two problems in these two scenarios.

Table 26. Average GAP values for the four problems in scenarios 0-3

Scenario	0	1	2	3
Characteristics considered /Objective formulation	4 work contracts and mono-skilled agents	4 work contracts and multi-skilled agents	6 work contracts and mono-skilled agents	6 work contracts and multi-skilled agents
Mono TC	<1%	<1%	3.7%	3.0%
Mono MC	<1%	<1%	<1%	<1%
Mono PR	<1%	<1%	<1%	<1%
Multi	<1%	<1%	3.6%	3.6%

GAP value: the relative gap between the best bound (the objective value of the best node remaining) and the best integer objective obtained

Table 27. GAP distribution for the four problems in scenarios 0-3

Scenario	0			1			2			3		
Charac. Considered	4 work contracts and mono-skilled agents			4 work contracts and multi-skilled agents			6 work contracts and mono-skilled agents			6 work contracts and multi-skilled agents		
Objective formulation	<1%	1-5%	>5%	<1%	1-5%	>5%	<1%	1-5%	>5%	<1%	1-5%	>5%
Mono TC	30	0	0	30	0	0	0	25	5	0	28	2
Mono MC	30	0	0	30	0	0	30	0	0	30	0	0
Mono PR	30	0	0	30	0	0	30	0	0	30	0	0
Multi	30	0	0	30	0	0	3	19	8	3	20	7

The average calculation times (Table 28) again confirm the efficiency of the resolution method on the four problems in the first two scenarios, and the two mono-objective problems with MC and PR in the last two scenarios. The calculation times are quite small (less than 30 minutes) for these problems in these scenarios. Moreover, the results also show that the mono-objective problem with TC and the multi-objective problem in the last two scenarios (6 work contracts, mono-skilled agents, and multi-skilled agents) are the most complex among all the problems studied, which need almost the maximum calculation time of 10 hours allowed.

Table 28. Average calculation time for the four problems in scenarios 0-3 (minutes)

Scenario	0	1	2	3
Characteristics considered /Objective formulation	4 work contracts and mono-skilled agents	4 work contracts and multi-skilled agents	6 work contracts and mono-skilled agents	6 work contracts and multi-skilled agents
Mono TC	1.1	0.9	600.0	597.4
Mono MC	1.2	1.9	6.8	4.7
Mono PR	0.6	0.9	21.2	15.2
Multi	1.0	1.3	506.6	487.1

It is not surprising that the problems in the case of 6 contracts are more complex than those in the case of 4 contracts. Because the weekly capacity of a 4x20 agent is only two-thirds of a 12x36 agent (see Table 16 and Table 11) and we consider the same total work capacity for the two cases, we have a greater number of agents in the case of 6 contracts, thus a greater number of possible combinations between them. Considering 6 contracts, therefore, increases the solution space and the complexity of problem solving. For the last two scenarios, the reason why the resolution method is more efficient for the mono-objective problems with MC and PR than for the mono-objective problem with TC and the multi-objective problem (which includes TC, MC, and PR) is that the complexity in terms of optimization for the first two problems is lower. For the mono-objective problem with TC or the multi-objective problem, in order to optimize the total transport costs (TC), the branch and bound algorithm of CPLEX has to search for an optimal solution between a huge number of feasible solutions whose objective values (TC) are very close. This increases the calculation time to cut a "bad" branch and jump into a new branch with a better objective value. By contrast, for the mono-objective problems with MC and PR, it is much easier to cut a "bad" branch when the objective values of feasible solutions are not quite close.

Another conclusion that we can extract from these three tables is that using multi-skilled agents instead of mono-skilled agents increase the number of feasible solutions for the problem but this increase is not quite important in comparison to the introduction of the two new work contracts. In the next three sections, we compare the quality of the solutions obtained in the four scenarios, which correspond to the considerations of no lever, of only lever 1 (multi-skilled agents), of only lever 2 (introduction of two new work contracts), and of both the levers at the same time.

5.5.2. Mono-skilled agents vs multi-skilled agents

For these experiments, we aim at comparing the quality of the solutions obtained in the two scenarios with and without the use of multi-skilled agents. This comparison is performed in two contexts with and without the second lever (two new contract types). In each context, we solve the four problems for the 30 instances in the two corresponding scenarios to obtain the values of the criteria considered. We then calculate, for each instance, percentages of improvement of these criteria in the case of using multi-skilled agents in comparison to the case using only mono-skilled agents. The average percentage of improvement for the 30 instances is used to evaluate the quality of the solutions of the four problems (Table 29).

Table 29. Criteria's improvement considering multi-skilled versus mono-skilled agents

Scenarios considered		1 vs 0	3 vs 2
Objective formulation	Criterion	4 work contracts, multi- versus mono-skilled agents	6 work contracts, multi- versus mono-skilled agents
Mono TC	TC	+1.9%	+2.3%
Mono MC	MC	+5.4%	+2.0%
Mono PR	PR	+3.5%	+3.3%
Multi	TC	+1.5%	+1.7%
	MC	+3.2%	+1.4%
	PR	+3.9%	+2.2%

The results of experiments (Table 29) show that in comparison to the scenarios considering only mono-skilled agents, those considering multi-skilled agents (4 or 6 contracts) always give solutions with slightly better TC, MC, and PR for all three mono-objective problems (between 1.9% and 5.4%). Moreover, the solutions obtained when considering multi-skilled agents also have a better compromise between the three criteria for the multi-objective problems with percentages of improvement between 1.4% and 3.9% for all the criteria. This is reasonable because using multi-skilled agents increases the number of alternatives for each problem's solution. The alternatives can be obtained when replacing an agent by another agent having the same skill type (as in the case of mono-skilled agents) or by an agent with multiple skills with one of them being the required skill. Therefore, the solution space in the case of multi-skilled agents is larger than and includes that in the case of mono-skilled agents. Therefore, when the calculation time is long enough to explore all the solutions to find the optimal solution, we can always find a better solution in the case of multi-skilled agents than in the case of mono-skilled agents. In conclusion, considering the multi-skilled agents gives a positive impact on both the costs for the company and agents' satisfaction related to the workload balance between them and their preferences for work periods. Therefore, the company should register multiple skills for each agent instead of only one main skill currently. Moreover, agents with multiple skills should be prioritized for recruitment in comparison to mono-skilled agents.

5.5.3. Four work contracts vs six work contracts

For these experiments, we investigate the second lever, the introduction of the two new contracts, in the two contexts with and without the first lever (multi-skilled agents). Similarly to the first experiments, we also use the average percentages of improvement for the 30 instances between the two scenarios in two contexts to evaluate the quality of the solutions obtained for the four problems (Table 30).

Table 30. Criteria's average improvement considering six versus four work contracts

Scenarios considered		2 vs 0	3 vs 1
Objective formulation	Criterion	mono-skilled agents, 6 versus 4 work contracts	multi-skilled agents, 6 versus 4 work contracts
Mono TC	TC	-3.4%	-2.9%
Mono MC	MC	+3.2%	+0.6%
Mono PR	PR	+46.4%	+46.6%
Multi	TC	-11.7%	-11.6%
	MC	+3.0%	+1.9%
	PR	+41.9%	+41.3%

The experiment results (Table 30) show that in comparison to the two scenarios using 4 work contracts, those using 6 work contracts give the solutions with slightly better MC values for the mono-objective problem with MC and the multi-objective problem (about 3% in the context of mono-skilled agents and 1% in the context of multi-skilled agents). Moreover, they give solutions with significantly better PR values for the mono-objective problem with PR and the multi-objective problem (between 41-46% for both the contexts with mono-skilled and multi-skilled agents). However, the TC values obtained when using six contracts (mono-skilled or multi-skilled agents) is slightly worse for the mono-objective problem with TC and considerably worse for the multi-objective problem (about 3% and 11% respectively). These results are explicable because to perform the same task, we need more 4x20 and 8x24 agents than 12x36 agents. The total number of agents (also the total number of work trips) in the scenarios using six work contracts is, therefore, larger than those when using only 4 work contracts. It is obvious that the total travel costs TC of a larger number of agents (or a larger number of work trips) are larger. However, 4x20 agents are much more flexible than 12x36 agents; each can work with another 4x20 agent to perform an 8-hour task or with two 4x0 agents or one 8x24, 5x2, 6x1 or 5x1 agent to perform a 12-hour task, etc. Moreover, he/she has very flexible start and end times per day and a flexible number of workdays per week that also increase his/her ability to combine with other contracts. This flexibility makes it possible to find an assignment that can increase the total preferences for all the company agents. Besides, having many possible task choices also allows them to fulfill their required workload easily so that they can reduce their modulation counters. These findings are quite interesting for the company when the new solutions have a better compromise between the three criteria considered than before. A limited increase in the costs of the company (about 11%) can significantly improve the satisfaction of their agents through a slight increase of 3% of the workload balance between the agents and a significant increase of 41% of their preferences for work periods.

5.5.4. Four Mono-skilled work contracts vs six multi-skilled work contracts

For these experiments, we aim at investigating the impact of using the two levers at the same time on the quality of solutions (scenario 3). We compare first the results with the original scenario and then with scenarios 1 and 2 that correspond to the considerations of each of these two levers separately. With the first comparison, we do not consider only the average improvement of the 30 instances but the improvement of all these 30 instances. By looking at all 30 instances, we want to see if the behavior of some instances is different from the others.

Scenario 3 considering the two levers is compared with the original scenario through the criteria's percentages of improvement of all 30 instances and five indicators associated (average, median, min, max, and standard deviation) (see Table 31). In this table, a positive (respectively negative) value means that scenario 3 gives a better (respectively worse) value for a criterion in comparison to the original scenario.

Table 31. Criteria's improvement using six multi- versus four mono-skilled contracts

Problem	Mono TC	Mono MC	Mono PR	Multi		
Improvement /Instance	of TC	of MC	of PR	of TC	of MC	of PR
1	-5.6%	9.2%	69.0%	-20.2%	9.5%	79.0%
2	-1.5%	0.0%	60.5%	-16.3%	0.0%	51.5%
3	-7.6%	22.9%	46.8%	-20.5%	21.7%	42.9%
4	3.6%	0.0%	53.2%	-10.7%	-1.7%	49.7%
5	-4.2%	0.0%	44.2%	-10.3%	0.0%	29.4%
6	-6.2%	0.8%	51.8%	-18.3%	3.0%	44.5%
7	1.3%	43.9%	76.6%	-16.2%	43.9%	73.2%
8	0.0%	-8.3%	51.5%	-13.6%	-8.3%	49.7%
9	-6.2%	-24.7%	45.2%	-18.4%	-33.3%	38.0%
10	1.5%	0.0%	46.2%	-3.0%	0.0%	42.6%
11	-0.8%	0.0%	55.4%	-6.2%	0.0%	47.5%
12	2.7%	7.8%	45.8%	-3.9%	0.0%	43.8%
13	1.4%	3.2%	21.4%	0.4%	3.2%	9.9%
14	-1.8%	0.0%	37.9%	-4.5%	0.0%	32.6%
15	-2.3%	-0.4%	30.3%	-5.5%	0.2%	27.4%
16	9.5%	0.0%	40.3%	2.8%	0.0%	37.8%
17	-0.5%	-0.3%	51.1%	-6.2%	0.0%	49.4%
18	-0.1%	0.0%	38.3%	-4.0%	-0.2%	35.9%
19	-1.0%	1.8%	50.9%	-7.8%	-2.3%	50.6%
20	1.8%	0.0%	34.5%	-5.0%	0.0%	34.5%
21	6.9%	9.6%	29.2%	-4.6%	9.2%	28.7%
22	0.1%	0.0%	43.2%	-4.8%	-1.6%	42.9%
23	-3.2%	80.9%	34.3%	-15.9%	99.1%	10.7%
24	-3.8%	-0.8%	54.7%	-8.6%	-0.8%	47.1%
25	0.9%	0.0%	32.7%	-5.6%	0.2%	30.4%
26	-3.8%	-5.2%	78.9%	-17.2%	-21.3%	73.6%
27	0.6%	39.1%	65.7%	-15.1%	39.1%	59.2%
28	-3.4%	-6.3%	45.2%	-15.0%	-5.8%	39.3%
29	-7.2%	0.0%	59.8%	-15.4%	0.0%	47.0%
30	-6.4%	-11.9%	43.8%	-20.6%	-11.9%	38.8%
Average	**-1.2%**	**5.4%**	**47.9%**	**-10.3%**	**4.7%**	**42.9%**
Median	**-0.9%**	**0.0%**	**46.0%**	**-9.4%**	**0.0%**	**42.9%**
Min	**-7.6%**	**-24.7%**	**21.4%**	**-20.6%**	**-33.3%**	**9.9%**
Max	**9.5%**	**80.9%**	**78.9%**	**2.8%**	**99.1%**	**79.0%**
STD	**4.0%**	**19.3%**	**13.5%**	**6.7%**	**22.8%**	**15.5%**

The results show that the percentages of improvement of PR are always positive for all the mono-objective and multi-objective problems for all 30 instances considered. This finding confirms the interest of using the two levers to improve agents' preferences for work periods.

Then, the percentages of improvement of TC in the mono-objective problem with TC are sometimes slightly positive, sometimes slightly negative with an average and a median near zero. The two levers are, therefore, not quite interesting for the improvement of TC. The most variable criterion between the 30 instances among the three criteria considered is MC for all the mono-objective and multi-objective problems where the standard deviations of the percentages of improvement for the 30 instances are 19.3% and 22.8% respectively. Moreover, the median and average values of the percentages of improvement for the 30 instances are zero or near-zero while the min and max values are significantly negative and distinctly positive. These results show that the two levers may be interesting for the improvement of MC in the mono-objective problem with MC or the compromise between TC, MC, and PR in the multi-objective problem. However, further experiments should be performed to find the reason for the high variability of MC between the instances and for the significant number of instances with no improvement of MC.

Table 32. Criteria's average improvement by the levers considered

Scenarios considered		1 vs 0	2 vs 0	3 vs 0
Objective formulation	Lever /Criterion	4 work contracts, multi- vs mono-skilled agents	mono-skilled agents, 6 vs 4 work contracts	6 work contracts, multi-skilled agents vs 4 work contracts, mono-skilled agents
Mono TC	TC	+1.9%	-3.4%	-1.20%
Mono MC	MC	+5.4%	+3.2%	+5.40%
Mono PR	PR	+3.5%	+46.4%	+47.90%
Multi	TC	+1.5%	-11.7%	-10.30%
Multi	MC	+3.2%	+3.0%	+4.70%
Multi	PR	+3.9%	+41.9%	+42.90%

The average improvement of all three criteria of the four problems in the case of using both the levers are better than when using the second lever only (Table 32). For the three mono-objective problems, the three criteria TC, MC, and PR are, on average, improved by 2.2%, 2.2%, and 1.5% more than when considering only the second lever. In comparison to the consideration of the first lever only (use of multi-skilled agents), the improvement of TC when considering both the levers is worse than for both the mono-objective problem with TC and the multi-objective problem. However, the improvement of MC and PR is slightly and distinctly better for the mono-objective problems with MC and PR and the multi-objective problem. This result means that a better compromise between the criteria is obtained when considering both levers. The company can, therefore, implement these two levers at the same time without worrying that one limits the impact of the other.

In summary, among the four scenarios 0 to 3 that correspond to the combinations between the two levers proposed, solutions obtained in scenario 1 (respectively 3) dominate those of scenario 0 (respectively 2). Therefore, the two best scenarios are scenarios 1 and 3. Depending on the objective of the company, these two scenarios can be chosen. If the travel costs are important and the company does not want to sacrifice this criterion to improve agents' satisfaction, scenario 1 is better. By contrast, if the company can accept a reasonable loss of the travel costs to significantly improve agents' satisfaction, scenario 3 is more reasonable.

For the next part of the experiments, we choose to work with scenario 3, which considers both the 6 work contracts and the multi-skilled agents and is the best in terms of compromise between the three criteria for the company. We will then investigate the impact of the three ways to model the dependence between planning horizons.

5.6. Three approaches to model the dependence between planning horizons

As mentioned in Section 5.4.2, among the three approaches to model the dependence between planning horizons, the independent case is not quite realistic when it assumes that all the resources used for planning are always available at the beginning of the planning horizon. This simplification approach is commonly found in the literature but cannot be used to make real planning for the company. The "fully" dependent case, which is currently considered by many companies, is realistic but quite constrained and when the demands are variable, problem solving may become infeasible. The use of this approach is, therefore, quite limited. The new approach proposed, the dependent case with buffer zones, is a compromise between the first two approaches. It is realistic and not so constrained. Moreover, besides the addition of the buffer zones between planning horizons, we increase the flexibility of all the work contracts by allowing a flexible number of break hours (respectively days off) between 2 sets of consecutive work shifts (respectively days) (see Section 5.2.2.3) which also contributes to reducing the constraints of this consideration of dependence.

We consider three parts of the experiments. The first part investigates the feasibility and complexity of problem solving in the three scenarios 3-5 corresponding to these three types of dependence. In the second part, we study the quality of the solutions obtained in these three scenarios. The last part is dedicated to the analysis of agents' buffer zones use.

5.6.1. Feasibility and complexity of problem solving

Table 33 shows that, among the three scenarios 3-5, scenario 4, corresponding to the "fully" dependent case, is quite constrained; we could not find a feasible solution within 10 hours for about a third of the instances. This finding is coherent with our pre-assessment that the "fully" dependent case is the most constrained among the three scenarios. The reason is that except for the flexible 4x20 contract, the availability of an agent of the five other contracts in the current planning horizon completely depends on what he/she did on the last horizon. Considering the "fully" dependent case, therefore, significantly reduces the solution space of the problem. Besides, in most of the instances where a feasible solution is obtained, the number of 4x20 agents is significant in comparison to the other contracts. This means that using flexible work contracts can help increase the chance to find a solution for the "fully" dependent case, which is currently considered by many companies in this domain. In the next parts of the experiments, we only focus on the two scenarios 3 and 5 (independent case and dependent case with buffer zones) in which a solution can be obtained for all 30 instances considered. First, we investigate the complexity of problem solving and then the quality of the solutions obtained in these two scenarios.

Table 33. Number of instances for which a feasible solution is obtained

Type of dependence	Independent	"Fully" dependent	Dependent with buffer zones
Number of instances	30/30	21/30	30/30

The complexity of problem solving in the two scenarios is considered through the numbers of instances among 30, in which the GAP value of the solution obtained is less than 1% (optimal solution), between 1% and 5% (near-optimal solution), and greater than 5% (far-optimal solution). The more instances for which the solution obtained is near-optimal or far-optimal, the more complex the problem solving is.

The results, Table 34, show that the complexity of problem solving in the two scenarios is not quite different for all three mono-objective problems with TC, MC, and PR. The numbers of instances, for which the solutions obtained are optimal, near-optimal, and far-optimal, are almost the same for the three problems. For the multi-objective problem, the complexity of problem solving is higher in the case of dependence with buffer zones than in the independent case where the number of far-optimal cases is significantly higher. The reason is that the number of feasible solutions in the case of dependent with buffer zones might be larger than those in the independent case. When the problems considered are not quite complex (mono-objective problems), the branch-and-bound Cplex algorithm can find the optimal/ near-optimal solutions in the predefined calculation time. However, when the problem is more complex (in the case of the multi-objective problem), the algorithm is not capable of exploring all the nodes of the solution tree to find the optimal solution in limited calculation time. Moreover, when the number of feasible solutions is larger (in the case of dependence with buffer zones), the optimality of the solution obtained is obviously lower when using the same calculation time.

Table 34. GAP distribution considering independent and dependent with buffer zones

Type of dependence	Independent			Dependent with buffer zones		
Objective formulation	<1%	1-5%	>5%	<1%	1-5%	>5%
Mono TC	0	28	2	2	26	2
Mono MC	30	0	0	29	0	1
Mono PR	30	0	0	30	0	0
Multi	3	20	7	4	13	13

5.6.2. Quality of the solutions

In order to compare the quality of the solutions obtained in the two scenarios, we calculate the percentages of improvement (PI) of TC, MC, and PR in the case of dependence with buffer zones (scenario 5) in comparison to the independent case (scenario 3) for the four problems and all 30 instances. Their mathematical formulations are as follows:

- $PI_{TC} = -\frac{TC_{dpz} - TC_{ind}}{TC_{ind}} x100\%$, where TC_{dpz} is TC in the case of dependent with buffer zones and TC_{ind} is TC in the case of independent.

- $PI_{MC} = -\frac{MC_{dpz} - MC_{ind}}{MC_{ind}} x100\%$, where MC_{dpz} is MC in the case of dependent with buffer zones and MC_{ind} is MC in the case of independent.

- $PI_{PR} = \frac{PR_{dpz} - PR_{ind}}{PR_{ind}} x100\%$, where PR_{dpz} is PR in the case of dependent with buffer zones and PR_{ind} is PR in the case of independent.

For the percentages of improvement of the travel costs (PI_{TC}) and the modulation counter (PI_{MC}), because we search to minimize TC and MC, the sign of PI_{TC} and PI_{MC} are the opposites of the relative changes of TC and MC in the formulations above (negative signs).

The results are given in Table 35. A positive (resp. negative) value means that the dependent with buffer zones is better (resp. worse) than the independent case for the criterion considered.

The results show that for the mono-objective problems with TC and PR, the values of TC (respectively PR) are not quite different (respectively slightly different) between the two scenarios for all 30 instances. The difference between the min and max values of TC (respectively PR) of the two scenarios is very small (respectively quite small) for these two problems. The average value of TC for the 30 instances is almost the same between the two scenarios. However, the average value of PR is slightly better in the case of dependence with buffer zones than in the independent case (1.8%). These results mean that the quality of the solutions of the two mono-objective problems with TC and PR in the case of dependence with buffer zones is at least as good as that of the independent case. For the mono-objective problem with MC, the improvement of MC in the case of dependence with buffer zones in comparison to the independent case is quite different between instances: for some instances, MC is slightly worse in the case of dependence with buffer zones but for many others, MC is significantly better. On average, MC is better in the case of dependent with buffer zones than in the independent case (17% on average). This result means that the case of dependence with buffer zones might be better than the independent case in improving MC value.

Table 35. Criteria's improvement considering dependence with buffer zones versus independent

Problem	Mono TC	Mono MC	Mono PR	Multi		
Improvement Instance	of TC	of MC	of PR	of TC	of MC	of PR
1	1.4%	13.6%	0.7%	-3.8%	2.6%	0.0%
2	-0.5%	0.0%	3.6%	-3.7%	-8.0%	4.3%
3	0.0%	0.0%	0.0%	-0.8%	-0.1%	3.6%
4	-0.8%	-0.5%	0.0%	-6.8%	1.7%	0.0%
5	-1.0%	0.0%	-1.2%	-1.0%	0.0%	-1.5%
6	-1.2%	10.7%	-1.5%	-1.5%	-6.7%	-1.7%
7	-0.8%	2.7%	1.1%	1.2%	-1.6%	-4.1%
8	2.1%	72.3%	0.0%	-3.9%	66.9%	0.0%
9	0.2%	144.7%	0.0%	-5.6%	29.2%	-2.8%
10	0.4%	0.0%	4.9%	-2.8%	0.0%	7.4%
11	-0.5%	0.0%	4.1%	1.7%	0.0%	8.1%
12	-0.3%	0.0%	1.2%	0.7%	-2.8%	-1.9%
13	2.4%	-12.5%	0.6%	-2.5%	-12.5%	8.4%
14	-0.3%	0.0%	2.1%	0.9%	0.0%	2.8%
15	1.3%	0.4%	1.3%	0.2%	0.0%	1.4%
16	0.0%	0.0%	1.3%	0.8%	0.0%	-1.4%
17	0.0%	0.3%	1.6%	1.7%	0.0%	-2.9%
18	0.2%	-0.2%	2.8%	-0.7%	0.2%	2.5%
19	0.1%	0.0%	6.4%	0.2%	0.0%	0.0%
20	-0.3%	0.0%	3.1%	0.6%	0.0%	-1.4%
21	1.7%	0.0%	8.1%	0.0%	0.4%	4.9%
22	-0.6%	0.2%	2.0%	-1.0%	0.0%	-1.1%
23	3.5%	-9.1%	0.0%	-3.0%	-9.1%	10.4%
24	0.1%	0.8%	1.9%	-0.8%	0.0%	10.3%
25	0.6%	0.0%	6.7%	4.1%	0.0%	5.1%
26	-0.3%	53.8%	3.6%	-8.7%	13.1%	-22.9%
27	0.6%	59.3%	0.0%	-4.4%	39.9%	-16.5%
28	-1.7%	72.3%	0.0%	-8.7%	46.6%	-3.7%
29	-1.0%	49.0%	0.0%	-10.5%	49.0%	7.7%
30	-0.2%	72.3%	0.0%	-1.4%	52.3%	-8.1%
Average	**0.2%**	**17.7%**	**1.8%**	**-2.0%**	**8.7%**	**0.2%**
Median	**0.0%**	**0.0%**	**1.2%**	**-1.0%**	**0.0%**	**0.0%**
Min	**-1.7%**	**-12.5%**	**-1.5%**	**-10.5%**	**-12.5%**	**-22.9%**
Max	**3.5%**	**144.7%**	**8.1%**	**4.1%**	**66.9%**	**10.4%**
STD	**1.1%**	**35.5%**	**2.4%**	**3.4%**	**20.8%**	**7.1%**

For the multi-objective problem, on average, the solutions obtained have a better compromise between TC, MC, and PR when TC is slightly worse (2%) while MC is significantly better (8.7%) and PR is almost the same in the two scenarios. However, this compromise is not the same for all

30 instances. The number of instances, in which the compromise between the three criteria is the same in the two scenarios, is significant. Moreover, we found three instances (2, 13 and 23) in which both MC and PR are worse than in the case of dependent with buffer zones, 5 instances (8, 27-30) in which MC is significantly larger (>30%) in the case of dependent with buffer zones. These results show that the dependence with buffer zones might be interesting in improving the compromise between the three criteria.

Briefly, it seems that the quality of the solutions obtained when considering the dependence with buffer zones is at least as good as that of the independent case, especially for MC values. The reason for this improvement of quality is that the agent flexibility considered in the two scenarios is different. In the independent case, the first workday and period of all the agents are very flexible, an agent can start his first work period very late as long as he/she can fulfill his/her minimum workload allowed on the horizon. This consideration even gives the agents higher flexibility than in the case of dependence with buffer zones when each agent has to start their first period within his/her buffer zone, even if it is not realist regarding his/her work contract. However, the consideration of a flexible number of break hours /days off between two sets of consecutive work shifts/days (see Table 17) allows compensating for the lower flexibility concerning the first workday and period. This second consideration of flexibility seems to have a greater impact on MC value than the first consideration. It allows the agents to perform a broader range of workload with a smaller minimum and a larger maximum possible workload per week (Table 17 in comparison to Table 16 and Table 11). The Cplex algorithm can, therefore, choose an appropriate workload per week for each agent to minimize the modulation counter of his/her work time.

5.6.3. Analysis of the buffer zones use

In this part of the experiments, we aim at evaluating, for all four problems, the use of buffer zones depending on different contracts. This evaluation is based on two indicators, including the proportion of agents using buffer zones (PAB) and the average buffer size per agent (ABS). Below are the mathematical formulations to calculate them.

$$\text{PAB} = \frac{\text{Number of agents using at least one buffer}}{\text{Number of used agents}}$$

$$\text{ABS} = \frac{\text{Total duration of used buffers}}{\text{Number of used agents}}$$

The results are given in Table 36.

Table 36. Analysis of the buffer zones use depending on agent contracts

Problem	Indicator	12x36 contract			8x24 contract		
		Average	Min	Max	Average	Min	Max
Mono TC	PAB	24%	0%	67%	82%	33%	100%
	ABS	2.6h	0h	6h	10.8h	2.7h	16h
Mono MC	PAB	73%	33%	100%	84%	50%	100%
	ABS	10.2h	2h	14.5h	11.1h	4h	16h
Mono PR	PAB	56%	0%	100%	97%	78%	100%
	ABS	7.9h	0h	16h	12.8h	8h	19h
Multi	PAB	53%	0%	100%	90%	25%	100%
	ABS	7.0h	0h	13.2h	12.6h	2h	20h

PAB: proportion of agents using buffer zones, ABS: average buffer size (hours/days) per agent

We first find out that buffer zones are only used by agents with shift contracts (12x36 and 8x24), not by those with non-shift contracts (5x2, 6x1, and 5x1) for all four problems. This is because the smallest buffer size for an agent with a non-shift contract is one day while it is one period of 4 hours for an agent with a shift contract. The possible buffer sizes and the possible numbers of work hours per week of an agent with a shift contract can, therefore, vary more widely than those of an agent with a non-shift contract (see Table 17, page 92), which facilitates the use of buffers.

Then, of the two shift contracts, the proportion of agents using buffers and the average buffer size are, on average, higher for the 8x24 contract than the 12x36 contract for all four problems. Moreover, at least 25% of the 8x24 agents of any instance use buffers and on average, more than 80% of these agents use buffers. The reason may be due to the length of a work shift of these two contracts and thus their ability to combine with other contracts to fulfill tasks when considering buffers. An agent with the 8x24 contract has a work-shift length of 8 hours, which allows him/her to combine easily with all other contracts to perform tasks with different duration. The use of buffers may facilitate more these combinations. By contrast, a work–shift length of 12 hours makes it harder than for an agent with the 12x36 contract to combine with others even with buffers.

After that, of the four problems considered, the values of the two indicators for both the 12x36 and 8x24 contracts in the multi-objective problem are a compromise compared to the three other problems. For this case, the proportion of agents using buffers and the buffer size are, on average, 53% and 7 hours for the 12x36 contract and 90% and 12.6 hours for the 8x24 contract, which means that the opportunity brought by buffer zones is often taken into account to find a better global solution. For the mono-objective problem with TC, using buffers does not have a significant impact on the minimization of TC. The things that matter are the proportions of different shift contracts (12x36, 8x24, and 4x20). The more agents with a small number of work trips per week (12x36 contract) are considered, the more likely the optimal TC is smaller. However, as explained before, buffers do have an impact on the ease of the combination between contracts to perform tasks, and are therefore used more often for 8x24 agents. For the mono-objective problem with MC, the buffers can help reduce agents' modulation counters, especially those with a positive last modulation counter, and thus are used by many 12x36 agents. For the mono-objective problem with PR, buffer zones can help to move agents' work shifts to the periods with higher preferences, and the corresponding indicators are quite similar to the multi-objective case.

Besides, we did not register any difference in the use of buffer zones between agents depending on their last modulation counters.

5.7. Conclusion

In this chapter, we consider the work team building and planning problem in the service-to-business domain in a context of variable demand, which is an extension of the problem in the context of stable demand presented in chapter IV. To cope with increasing numbers of new variable clients' demands, companies have to consider different ways to increase the adaptation of its workforce. We investigate two organizational levers and three ways to model the dependence between planning horizons to increase workforce adaptation. The two levers include the introduction of new flexible work contracts and the use of multi-skilled agents. The three ways to model the dependence between planning horizons include independent, "fully" dependent, and our proposition, dependent with buffer zones. Agents' skills relate to both the nature of skill (i.e. cleaning, concierge, and surveillance) and the workplace (i.e. hospital, shop, and factory) while the skill levels relate to managerial levels (i.e. supervisor, leader, and worker). One of the two new flexible work contracts proposed is a flexible part-time contract with 28 hours per week who can work a maximum of 12 hours per day and start his/her workday at any time. We consider the annualized work-hours approach where a modulation counter is used to measure the accumulated difference between agents' real and contract work times on several consecutive planning horizons. This consideration allows agents to have different numbers of work hours on different planning horizons and thus increase their flexibility. Besides, three new characteristics including agents' last workday, period, and days off on the previous horizon, are considered in the case of dependent with buffer zones. These allow us to better handle the dependence between agents' activities between planning horizons by adding buffer zones between them.

To solve this problem, the company wants to attain three different objectives: minimizing its agents' travel costs (TC), maximizing the workload balance between them by minimizing the maximum absolute value of their modulation counters (MC), and finally maximizing their preference satisfaction for certain work periods (PR). The mixed-integer linear programming method was used to model and solve four different problems: three mono-objective problems with TC, MC, and PR respectively, and one multi-objective problem with a weighted sum of the three criteria. Thirty realistic instances, built on the real database provided by our Brazilian partner, were used to perform the numerical experiments. The results show that:

Our resolution method is capable of solving the problems with different real sizes whose the number of clients is less than or equal to 6, the number of tasks is less than or equal to 100, and the number of agents is less than or equal to 60. Among the four problems considered, the method is very efficient for the two mono-objective problems with MC and PR when they are solved optimally for all the instances considered. Besides, it is quite efficient for the mono-objective problem with TC and the multi-objective problem when for most of the instances considered, the two problems are solved optimally or near-optimally.

In terms of the quality of solutions obtained, considering multi-skilled agents slightly improves all three criteria considered for the mono-objective and the multi-objective problems. This conclusion is coherent with the findings of the literature when considering multi-skilled agents is generally found to increase the workforce flexibility (Parr and Thompson 2007; Rong and Grunow 2009; Stolletz and Zamorano 2014). Introducing two new work contracts gives a better compromise between these three criteria. It slightly degrades TC but slightly improves MC and significantly improves PR for all the mono-objective and multi-objective problems. This conclusion is also confirmed by the literature. (Bard 2004; Stolletz 2010) confirm the role of flexible contracts in covering variable demand. Then, allowing flexible break time between consecutive work shifts/days and the buffer zones between consecutive planning horizons increases the chance to find a feasible solution in comparison to the "fully" dependent case, which is commonly considered by companies when demand is stable. Moreover, these considerations give solutions with a slightly better compromise between the three criteria than those obtained in the independent case, which is not realistic but commonly used in the literature to simplify the problem. Besides, buffers are not used by agents with non-shift contracts, only those with shift contracts, especially the 8x24 contract. For any instance, at least 25% of the 8x24 agents use buffers and on average, more than 80% of them use buffers.

Chapter VI. Conclusions and perspectives

Résumé en français

Notre thèse porte sur le problème de constitution et de planification d'équipes de travail que l'on trouve souvent dans les sociétés de sous-traitance, fournissant des services sur site à des entreprises ou des particuliers. La société doit organiser ses agents en équipes pour satisfaire les demandes des clients. L'objectif est de constituer les équipes les plus appropriées et planifier leurs activités en fonction des tâches à réaliser, de plusieurs objectifs différents à atteindre, et de plusieurs contraintes internes et externes à respecter. Cinq questions de recherche ont été soulevées :

- Comment identifier et modéliser toutes les caractéristiques des demandes et des ressources, leurs dépendances, ainsi que les décisions d'affectation des ressources aux demandes en respectant de multiples contraintes ?
- Comment concilier des critères de performance économiques et sociétaux dans la planification ?
- Comment concilier la stabilité d'affectation dans le cas d'une demande régulière avec une optimisation globale ?
- Comment augmenter la flexibilité des ressources pour répondre aux demandes variables ?
- Dans le cas de demandes et de ressources variables d'un horizon de planification à l'autre, comment gérer la dépendance entre les horizons ?

Pour répondre à la première question, nous avons proposé, dans Chapitre II, un diagramme de classes générique, incluant cinq classes d'objets (clients, tâches, agents, itinéraires, et véhicules) et permettant d'identifier toutes les caractéristiques des demandes, des ressources, et des problèmes de décision. La plupart des caractéristiques de ces cinq classes d'objets proviennent des problèmes réels rencontrés dans le domaine du service aux entreprises au Brésil et du service aux particuliers en France. Les autres sont des caractéristiques classiques qui sont couramment étudiées dans la littérature. Parmi eux, les types et niveaux de compétences des agents pris en compte dans le domaine du service aux entreprises, la disponibilité de différents contrats de travail, en particulier les contrats flexibles, et les caractéristiques liées à la dépendance des activités des agents entre les horizons de planification sont des caractéristiques originales de notre problème. Chaque instanciation donne lieu à une variante du problème correspondant à une combinaison de prise de décision, de niveaux de variabilité des demandes, de niveaux de flexibilité des ressources, et d'indicateurs de performance économique ou sociétale. Chaque variante dispose d'un niveau de complexité différent et il est important d'adapter l'approche de modélisation à chaque variante spécifique plutôt que les traiter toutes de la même manière. Par exemple, lorsque les demandes sont stables, une planification cyclique sur une longue période est souvent considérée mais quand elles sont variables, une planification acyclique sur un horizon court est plus appropriée. Le Chapitre III complète cette caractérisation du problème par une analyse quantitative de la revue de littérature. Elle montre que, parmi les 4 sous-problèmes de prise de décision du problème généralisé, les combinaisons d'au moins deux sous-problèmes, comprenant l'affectation d'agents et la constitution d'équipes sont fréquemment considérées.

Pour répondre à la deuxième question, nous avons d'abord, dans Chapitre II, identifié des critères et les regroupé selon leur type de performance, incluant la performance économique et la performance sociétale. Les critères de performance économiques sont liés aux coûts de l'entreprise, tel que les coûts de déplacement au travail et de main-d'œuvre. Les critères de performance sociétaux sont relatifs à la satisfaction des clients, tel que le respect du délai de service et de leurs préférences pour certains agents, ou à la satisfaction des agents comme de l'équité de charge de travail entre eux, la durée de leur trajet domicile-travail et leurs préférences pour certaines périodes de travail. Dans les deux études de cas (chapitres IV et V), nous avons considéré la réconciliation de plusieurs critères différents. Chapitre IV a tenu compte des coûts de déplacement au travail et de la satisfaction des agents quant à la durée de leur trajet domicile-travail. Chapitre V a examiné les coûts de déplacement au travail et la satisfaction des agents liés à l'équité de la charge de travail entre eux et au respect de leurs préférences pour certaines périodes de travail. De plus, pour modéliser la conciliation entre ces critères, nous avons utilisé la méthode programmation linéaire multi objectif à variables mixtes. Pour faire face à l'optimisation multicritère, nous avons choisi la technique de la somme pondérée avec laquelle le poids de chaque critère dans la formulation multicritère peut varier et dépend de son niveau d'importance considéré par l'entreprise.

Pour répondre à la troisième question, nous avons étudié, dans le Chapitre IV, une variante du problème dans le contexte de demande stable correspondant à la situation actuelle d'une entreprise brésilienne. Nous avons proposé une approche de planification multicritère à deux niveaux: une planification hebdomadaire reconduite chaque semaine pour chaque ensemble des nouveaux clients de la même période et, à une fréquence moindre, une re-planification pour tous les clients actifs permettant une optimisation globale. L'expérimentation a montré la supériorité de notre planification hebdomadaire par rapport à la planification manuelle de l'entreprise. Elle donne la solution optimale avec un meilleur compromis entre les deux critères considérés, incluant les coûts de déplacements des agents pris en charge par l'entreprise et la satisfaction des agents associée à leur durée moyenne de voyage. De plus, elle a aussi montré l'intérêt de notre approche de planification à deux niveaux, y compris la re-planification, par rapport à une agrégation de plans de travail successifs obtenus par la planification hebdomadaire et sans changer les affectations agent-tâche.

Pour répondre à la quatrième question, à travers d'une revue approfondie du Chapitre III, nous avons identifié notamment des leviers organisationnels potentiels pour accroître la flexibilité des ressources. Dans le chapitre V, qui considère le problème dans un contexte de demande variable, nous avons spécifié trois leviers, incluant la combinaison des contrats de travail différents, la polyvalence des agents, et la considération des heures de travail flexibles des agents, et puis évalué leur impact sur le problème. Concernant la combinaison des contrats de travail, plusieurs contrats correspondant à des capacités journalières et hebdomadaires différentes sont considérés, incluant celui de type posté et non posté, celui flexible et inflexible, et celui à temps pleins et à temps partiel. Pour la polyvalence des agents, nous avons enregistré des compétences secondaires pour certains agents en plus de leur compétence principale. Ces compétences secondaires peuvent être leurs compétences personnelles disponibles avant d'être recrutées par l'entreprise ou celles qu'ils ont apprises au cours du processus de formation après le recrutement. Pour les heures de travail flexibles, nous avons utilisé l'approche des heures de travail annualisées. Un compteur de modulation est utilisé pour mesurer la différence entre les temps de travail réel et contractuel de chaque agent sur des horizons de planification consécutifs. Cette approche permet à tous les agents de travailler un certain nombre d'heures de plus ou de moins que leur temps de travail contractuel, en fonction de la demande réelle. Cependant, pour assurer l'équité de la charge de travail entre les agents lorsque la demande varie considérablement, minimiser la différence des compteurs de modulation entre les agents a été choisi d'être un critère de performance social du problème. Des expérimentations ont montré que la combinaison de deux nouveaux contrats flexibles, l'un à temps plein et l'autre à temps partiel, avec quatre contrats actuels, donne un meilleur compromis entre les critères considérés. L'utilisation des agents polyvalents améliore légèrement tous les critères considérés. L'approche des heures de travail annualisées assure, pour un certain niveau, l'équité de la charge de travail entre les agents.

Pour répondre à cinquième question, nous avons proposé, dans le Chapitre V, une approche de modélisation de la dépendance entre les horizons de planification « dépendant avec zones tampons », qui est intermédiaire entre indépendant et dépendant « pur ». La première est une approche classique mais n'est pas très réaliste quand elle considère l'hypothèse de simplificatrice selon laquelle toutes les ressources sont disponibles dès le début de l'horizon de planification; la deuxième correspond à une approche industrielle réaliste mais trop contrainte quand les activités d'un agent dans un horizon complètement dépendent de celles de l'horizon précédent. Des expérimentations numériques ont confirmé l'efficacité de notre approche par rapport à deux autres quand elle significativement augmente la chance de trouver une solution faisable par rapport au cas dépendant « pur ». En plus, elle donne des solutions avec un meilleur compromis entre les critères considérés par rapport au cas indépendant.

Par ailleurs, les résultats au-dessus donnent aux managers d'entreprises une aide à la décision pour améliorer leur méthode de constitution et planification des équipes dans des contextes différents. Pour la demande stable (chapitre IV), il n'est pas vraiment nécessaire de changer la manière manuelle de constitution d'équipes des entreprises. Par contre, la planification manuelle peut être améliorée en utilisant une méthode de planification basée sur l'optimisation telle que la planification à deux niveaux que nous avons proposée. Pour les demandes variables (chapitre V), il est en plus nécessaire de revoir la manière de constituer les équipes. Concrètement, selon le niveau de variabilité des demandes, des leviers différents devraient être utilisés pour augmenter le niveau d'adaptation de la main d'œuvre. En se basant sur ces résultats, des recommandations managériales peuvent être proposées aux entreprises pour améliorer leur stratégie de développement de la main d'œuvre, qui devrait concerner à la fois le recrutement, la formation et l'affectation. D'abord, elle devrait avoir une diversité de types de contrats, y compris des contrats postés et non-postés, à temps plein et à temps partiel, flexibles et réguliers. Puis, les agents polyvalents devraient être prioritaires pour le recrutement par rapport aux agents mono-compétence. La formation doit non seulement consolider la compétence principale d'un agent mais également développer ses compétences secondaires. Enfin, l'entreprise peut négocier avec les agents permanents pour augmenter la flexibilité de leurs horaires de travail en permettant un temps de pause flexible entre des postes / jours de travail consécutifs. Cependant, la règlementation doit être strictement respectée en négociant ces termes avec les agents.

Cinq directions peuvent être suivies pour améliorer notre travail, qui incluent la prise en compte complète de l'impact économique et social des leviers proposés, les nouvelles approches de modélisation et de résolution, les études sur des nouvelles variantes du problème et des problèmes stochastiques et dynamiques, et finalement le développement d'une approche généralisée pour la constitution et la planification d'équipes qui pourrait être appliquée pour diverses variantes du problème.

L'utilisation d'agents polyvalents peut nécessiter des coûts élevés de main-d'œuvre, de recrutement et de formation par rapport aux agents mono-compétence. Cependant, la lassitude au travail des agents polyvalents est inférieure à celle des agents mono-compétence, et la polyvalence peut augmenter la satisfaction des agents et la productivité de l'entreprise. L'utilisation de contrats flexibles et à temps partiel augmente la flexibilité de la main-d'œuvre mais réduit également sa stabilité car ces agents sont généralement moins fidèles que ceux des contrats à temps plein. La prise en compte des temps de pause flexibles et des zones tampons peut réduire la satisfaction des agents car le planning de travail de chaque agent peut être différent d'une semaine à l'autre et difficile à prévoir avec précision.

Avant de résoudre le problème, une évaluation générale de la charge de travail et de la capacité des agents peut être effectuée pour prédire à l'avance la faisabilité de la résolution du problème. Cela peut réduire le temps de calcul pour éviter de chercher des solutions pour des problèmes dont aucune solution faisable n'existe. En outre, nous utilisons actuellement une méthode de programmation linéaire en nombres mixtes pour modéliser et résoudre le problème. Cependant, afin de traiter des problèmes de grande taille, une méthode par approximation telle qu'un algorithme génétique ou le recuit simulé pourrait être envisagée pour donner des solutions de bonne qualité en peu de temps. Des frontières de Pareto pourraient être mises en œuvre pour obtenir les solutions avec différents niveaux de compromis entre les trois critères pour le problème multi-objectif par rapport à une formulation multi-objectif à somme pondérée unique comme nous l'avons fait. Quelques nouvelles hypothèses pourraient également être testées. D'abord, nous pouvons tenir compte du fait que les temps de trajet sont différents selon les périodes de la journée, et que les temps de trajet du domicile au travail et du travail au domicile sont différents. Puis, nous devrions utiliser des temps de déplacement et des coûts de déplacement plus précis entre le domicile des agents et leur lieu de travail, plutôt que ceux estimés. Enfin, l'utilisation de bus d'entreprise pour transporter les agents vers leur lieu de travail au lieu d'utiliser les transports en commun ou des moyens privés est une direction potentielle pour réduire le coût total des déplacements.

Le problème dans le domaine de services aux particuliers est généralement assez complexe en raison du grand nombre de problèmes de prise de décisions simultanément pris en compte et de la forte variabilité de la demande. Il mériterait donc une attention particulière.

Nous avons considéré, dans notre thèse, un problème déterministe où toutes les données utilisées pour la planification sont connues à l'avance. Cependant, dans la réalité, certaines situations imprévues, comme un temps de trajet plus long en raison de la congestion ou des demandes incertaines, peuvent se produire. Une planification stochastique qui prend en compte ces facteurs pourrait être envisagée. En outre, une autre direction consisterait à considérer que certaines caractéristiques du problème telles que la compétence des agents peuvent varier au cours du temps.

Une approche généralisée pour la constitution et la planification de la main-d'œuvre qui pourrait être appliquée à diverses variantes du problème pourrait être développée. Il s'agirait de proposer, pour chaque combinaison d'un type de client (entreprise ou particulier), des problèmes de prise de décisions considérés, du niveau de variabilité des demandes, du nombre d'objectifs et de leurs poids, et des contraintes considérées, plusieurs scénarios avec des manières différentes de constituer les équipes de travail. Chaque scénario préciserait les contrats flexibles considérés et leurs proportions, le pourcentage d'agents polyvalents, le niveau de flexibilité des contrats permanents, le nombre total d'agents et la proportion d'agents supplémentaires, et finalement le nombre maximum d'heures supplémentaires de chaque agent.

6.1. Conclusions

Our thesis deals with the work team building and planning problem that is commonly found in the subcontracting companies providing on-site services to businesses or individuals. The company has to organize its agents into work teams and create their work plans to fulfill clients' demands, taking into account different economic and social performance criteria, as well as multiple internal and external constraints. Five research questions were raised:

- How to identify and model all the demands' and resources' characteristics, their dependencies, as well as the decisions to assign the resources to the demands taking into account multiple constraints?
- How to reconcile economic and social performance criteria in planning?
- How to reconcile the assignment stability in the case of a regular demand with global optimization?
- How to increase the flexibility of resources to meet variable demand?
- When the demands and the resources vary from one planning horizon to another, how to manage the dependence of the work plans between the horizons?

To answer the first research question, we proposed, in Chapter II, a generic class diagram, including five classes of objects (clients, tasks, agents, travel routes, and vehicles), to identify all the characteristics of the demand, the resources (the agents), the decision-making problems, and the economic or social performance indicators. Most of the characteristics of the five classes of objects come from the real problems found in the service-to-business domain in Brazil and the service-to-individual domain in France. The remaining are classical characteristics that have been commonly studied in the literature. Among them, agents' skill types and levels considered in the service-to-business domain, the availability of different work contracts, and the characteristics related to the dependence of agents' activities between planning horizons, are original characteristics of our problem. Agents' skill types relate to both the nature of skill (i.e. cleaning, concierge, and surveillance) and the workplace (i.e. hospital, shop, and factory) while the skill levels relate to managerial levels (i.e. supervisor, leader, and worker). Regarding the availability of different work contracts, we characterized both shift and non-shift, full-time and part-time, regular, and flexible contracts. Among them, we proposed a new flexible part-time contract with 28 hours per week who can work a maximum of 12 hours per day and start his/her workday at any time. The consideration of annualized work hours where a modulation counter is used to measure the accumulated difference between agents' real and contract work times on many consecutive planning horizons. This consideration allows agents to have different numbers of work hours on different planning horizons and thus increase their flexibility. Besides, three new characteristics including agents' last workday, period, and days off on the previous horizon, allow us to handle better the dependence between planning horizons. With the generic diagram, each instantiation results in a problem variant corresponding to a combination of decision-making, levels of demand variability, levels of flexibility of resources, and performance indicators. Each variant has a different complexity and it is important to adapt the modeling approach to each specific variant rather than treating them all in the same way. For example, when the demand is stable, cyclic planning over the long term is often considered, but when it is variable, acyclic planning over a short horizon is more appropriate. Chapter III completed the characterization of the generalized problem of Chapter II with a quantitative analysis of the literature. It shows that, among the four decision-making sub-problems of the generalized problem, the combinations of at least two sub-problems, including the agent assignment and the team building, are frequently considered.

To answer the second question, we firstly identified in Chapter II all common criteria and regrouped them according to their type of performance, including economic and social performance. Economic performance criteria relate to the company's costs, such as agents' travel costs and workforce costs. The social performance criteria relate to clients' satisfaction, such as the respect of their preferences for certain agents, or agents' satisfaction such as the minimization of their work trip duration, the workload balance between them, or the respect of their preferences for certain work periods. In the two case studies (Chapters IV and V), we considered the reconciliation of several different criteria. Chapter IV took into account the company's travel costs and agents' satisfaction related to their work trip duration. Chapter V examined the company's travel costs and agents' satisfaction related to both the workload balance between them and the respect of their preferences work periods. Moreover, to model the reconciliation between these criteria, we used the multi-objective mixed integer linear programming method with the weighted sum technique. The weight of each criterion in the multi-objective formulation can vary and depends on its level of importance to the company.

To answer the third question, we considered, in Chapter IV, a variant of the problem in the context of stable demand corresponding to the current situation of our Brazilian partner. We proposed a multi-criteria planning approach with two levels: weekly cyclic planning repeated over a long term for each set of new clients of the same time span, and, at a lower frequency, re-planning for all active clients allowing global optimization. The experimentation, performed with data generated from our real benchmark, showed the superiority of our weekly planning in comparison to manual planning currently used by the company. It gives optimal solutions with a better compromise between the two criteria considered, including the agents' travel costs refunded by the company and agents' satisfaction associated with their average travel time. Besides, it also shows the interests of our two-level planning approach, including re-planning, in comparison to an aggregation of successive work plans obtained by weekly planning, and without changing the agent-task assignments.

To answer the fourth question, through an in-depth review of Chapter III, we identified potential organizational levers to increase the flexibility of resources in the context of variable demand. In Chapter V, we specified three levers, including the combination of different work contracts, the uses of multi-skilled agents, and their flexible work hours, and then evaluate their impact on the problem. Several contracts corresponding to different daily and weekly work capacities were considered, including the shift and non-shift types, the flexible and regular ones, and the full-time and part-time contracts. We took into account multi-skilled agents, by the registration of several skills for certain agents (instead of only their main skill). These skills can be available before being recruited by the company or those they learned during the training process after recruitment. Concerning the use of agents' flexible work hours, we considered the overtime approach under annualized work hours. With this approach, a modulation counter is used to measure the difference between the real and contract work times of each agent on many consecutive planning horizons. It allows all agents to work a certain number of hours more or less than their contract work time, depending on the real demand on that horizon. Besides, to ensure the workload balance between agents when demand varies widely, minimizing the difference of the modulation counters between agents was chosen to be an important social performance criterion. The advantages of these three organizational levers were verified by numerical experiments. The combination of two new flexible contracts, one full-time and the other part-time, with four current full-time contracts, gives a better compromise between the criteria considered.

The use of multi-skilled agents slightly improves all the criteria considered. The overtime approach under annualized work hours ensures, for a certain level, the workload balance between agents.

To answer the last question, we proposed, in Chapter V, a new approach to model the dependence between planning horizons "dependent with buffer zones", which is intermediate between independent and “fully” dependent. The first is a classic approach but is not very realistic when it considers the simplifying assumption that all resources are available from the start of the planning horizon. The second corresponds to a realistic but too constrained industrial approach when agents’ activities on a horizon completely depend on those of the precedent horizon. The numerical experiments confirmed the effectiveness of our approach in comparison to two others when it significantly increases the chance of finding a feasible solution in relation to the “fully” dependent case. In addition, it gives solutions with a better compromise between the criteria considered with respect to the independent case.

These findings above give the company’s managers decision-making support to improve their strategy for the business and workforce development. To cover services with daily and weekly variable demand, the organization of the company’s workforce has to be changed. Moreover, the planning for stable demand, the demands with low variability, and those with a high variability should be managed separately. For the current stable demand, it is not necessary to change the workforce organization. Instead, the company should focus on improving manual planning by using an optimization approach such as the two-level planning approach that we proposed. For variable demand, the company should focus only on the demand with moderate variability and build up its workforce based on these demands. The strategy for workforce development should concern both the recruitment and assignment. First, a good workforce should have a diversity of different contract types, i.e. shift and non-shift contracts, full-time and part-time, regular, and flexible contracts. Next, agents with multiple skills should be prioritized for recruitment in comparison to mono-skilled agents. After that, companies can negotiate with agents to increase the flexibility of their work schedules by allowing a flexible break time between consecutive work shifts/days. Finally, having agents work a flexible number of hours per week could be allowed and a reasonable proportion of extra agents could be considered.

6.2. Perspectives

This thesis work contributes to characterizing, modeling, and solving the work team building and planning problem. However, it should be only considered as a part of the study of this problem. Different directions can be followed to improve our work. We divide them into five categories, including the hidden economic and social impact of the levers proposed, new modeling and solving approaches, the consideration of new problem variants, the stochastic and dynamic problems, and the development of a generalized work team building and planning approach that can be used for various problem variants.

6.2.1. Hidden economic and social impacts of organizational levers

We investigated, in chapter V, different levers to increase the workforce adaptation to cover variable demand. Three criteria, which include agents' travel costs, the workload balance between them, and their satisfaction for certain work periods, were used to evaluate the impact of these levers. However, the company should also take into account some other hidden economic and social impacts of these levers:

- The use of multi-skilled agents has a positive impact on the company's travel costs and agents' satisfaction but maybe a negative impact on the salary costs, if these costs associated with multi-skilled agents are higher than those of the mono-skilled agents are. Moreover, training different skills for an agent may also be more expensive than training him/her only one skill. These salary and training costs could be considered together with the travel costs in the problem modeling. However, using multi-skilled agents can create a positive economic and social impact when a multi-skilled agent can work at different workplaces in different periods. This can reduce their lassitude at work, and thus increase their satisfaction and work efficiency. Briefly, different aspects related to the use of multi-skilled agents should be taken into account to obtain an appropriate proportion of multi-skilled agents.
- Using flexible and part-time contracts can increase workforce flexibility but also cause a problem of workforce stability when flexible and part-time contracts are usually less loyal to the company than the regular and full-time contracts. A reasonable proportion of agents with flexible and stable contracts should be obtained.

- The consideration of flexible break time between consecutive work shifts/ days and adding buffer zones between planning horizons increase workforce flexibility to cover variable demand. However, agents' weekly work schedules when considering the buffer zones can be quite different between weeks and cannot be well predicted in advance, which affects their personal plan and thus, their satisfaction.
- The agents' extra hours should be regulated to ensure their long-term work capacity.

6.2.2. Modeling and solving approaches

We are currently using a mathematical programming method, precisely the mixed integer linear programming, to model the two problem variants. The CPLEX optimization tool then solves these models. This solving method is efficient for with small-to-medium sizes problems, and when the calculation time is not an important criterion. In the service-to-business domain, these two conditions can be satisfied. First, different decomposition techniques can be used to reduce the problem size such as territorial or skill decomposition technique. Next, the demand is usually known a long time in advance and the company can use as much as 1 week to solve the problem. However, in order to solve a big-size problem, or when the planning horizon is very short and the long calculation time is not allowed anymore, an approximation method such as genetic algorithm, simulated annealing, or Tabu search should be considered to give good-quality solutions in short calculation time. Then, Pareto frontiers could be implemented to obtain solutions with different levels of compromise between the three criteria of the multi-objective problem rather than using a unique weighted sum multi-objective formulation as we did. Finally, some new hypotheses could also be tested:

- Travel times differ at different periods of a day and between the trips from home to work and from work back home. The congestion, happening in the morning when many agents leave for work and in the late afternoon when they go back home, increases their travel times, especially those using private means or buses. By contrast, the travel time is less for those leaving for work or going back home early in the morning, around noon, or in the late evening. This is however not true for those using tramway, train, or metro. The frequency of these transport means is higher during rush hours and lower for other periods.

- More precise travel times and travel costs between agents' homes and clients' workplaces rather than the average values between their living and working zones for the travel costs and the values generated by a normal distribution for the travel times. This will help improve the precision of the problem modeling and solving.
- Using the company's buses to transport agents to their workplaces instead of using public transport or private means is a potential way to reduce the total travel costs. However, an in-depth study should be performed to evaluate the performance of these two solutions

6.2.3. Problem in the service-to-individual domain

The work team building and planning problem was characterized for both the service-to-business and service-to-individual domains. We chose first to focus on the problem in the service-to-business domain. The problem in the service-to-individual domain is generally more complex than in the service-to-business domain. It takes into account all four decision-making problems that include also the vehicle routing problem where each agent has to travel to different clients' workplaces during a single day to provide the required services. Moreover, client demands are more variable and the planning horizon has to be considered shorter. It could be interesting to investigate in this case the impact of the organizational levers considered in the service-to-business domain.

6.2.4. Stochastic and dynamic problems

We considered, in our thesis, a deterministic problem where all the data used for planning are known an amount of time in advance. However, in reality, some unexpected situations, which can be related to the demands, such as longer travel and service times and uncertain demands, or the workforce, such as sickness, accident, and short notice leave, can happen at any time. Stochastic planning that takes into account these factors can be considered (Lei, Laporte, and Guo 2011; Yuan, Liu, and Jiang 2015). Besides, another direction is to consider that some problem characteristics can be time-dependent. (Chen, Thomas, and Hewitt 2016) consider that the skill level of an agent is dynamic and depends on his/her initial skill level at the recruit time and the number of tasks that he/she has performed since then. His/her skill changes over time and he/she can perform a task at a time only if his/her skill level is greater than that required by the task. However, the evolution of the agent skill is a long-term process and the two following research questions can be raised: how could we take into account this aspect in a short-term planning? and how could we obtain a compromise between the short-term gain in terms of agents' productivity and the long-term gain associated with the development of agent skills?

6.2.5. Generalized work team building and planning approach

We developed, for each of the two problem variants (chapters IV and V), a work team building and planning method that allows determining an appropriate combination of the resources with different characteristics to fulfill the required demands with certain variability, help the company obtain multiple objectives and meet its constraints. For future work, a generalized work team building and planning approach that can be applied to various problem variants could be developed. We can imagine a generalized approach that can propose, for each combination of the client type (business or individual), the decision-making problems considered, the demand variability, the objectives and their weights, and the constraints, several scenarios with different ways of building work teams. Each scenario would specify the flexible contracts and their proportions, the percentage of multi-skilled agents, the flexibility of the permanent contracts, the total number of agents and the proportion of extra agents, and the maximum number of extra hours of each agent. Different scenarios proposed could help the company managers to make a decision more efficiently, depending on the availability of their workforce. Finally, the next step when this generalized approach is already developed would be to integrate it into the information system of the company.

Appendix A. Extended results of the literature review

Table A.1. Number of articles considered in the literature by journal

Journal	**Number of papers**
Annals of Operations Research	4
Applied Soft Computing Journal	1
Canadian Journal of Administrative Sciences	1
Computer Methods and Programs in Biomedicine	1
Computer Science Interfaces Series	1
Computers & Industrial Engineering	5
Computers & Operations Research	7
Decision Sciences	2
EURO Journal on Transportation and Logistics	1
European Journal of Operational Research	20
Expert Systems with Applications	2
Flexible Services and Manufacturing Journal	1
Health Care Management Science	4
IBM Journal of Research and Development	1
IEEE Transactions on Evolutionary Computation	1
IIE Transactions	3
Informatica/ Interfaces / Operations Research / Sustainability	1
INFORMS Journal on Applied Analytics	1
INFORMS Journal on Computing	2
International Journal of Advanced Manufacturing Technology	1
International Journal of Production Economics	2
International Journal of Production Research	2
International Transactions in Operational Research	1
Journal of Applied Operational Research	1
Journal of Heuristics	2
Journal of Mathematical Modelling and Algorithms	1
Journal of Medical Systems	1
Journal of Network and Computer Applications	1
Journal of Scheduling	7
Journal of the Operational Research Society	4
Manufacturing & Service Operations Management	1
Mathematical Modelling	1
Omega	6
Optimization Letters	1
Procedia Computer Science	1
Reliability Engineering and System Safety	1
Transportation Research	7
Transportation Science	1
Conference communications	16
Total	**119**

Table A. 2. Extended results of Table 3 - number of articles by sector

Sectors	Nb of articles	Articles
General	**15**	[Aickelin, Burke, and Li, 2009]; [Alfares, 2003]; [Al-Yakoob and Sherali, 2007]; [Anoshkina and Meisel, 2019]; [Azmat, Hurlimann, and Widmer, 2004]; [Azmat and Widmer, 2004]; [Cowling et al., 2006]; [Dohn, Kolin, and Clausen, 2009]; [Garaix et al., 2018]; [Jacobs and Bechtold, 1993]; [Laporte and Pesant, 2004]; [Naveh et al., 2007]; [Restrepo, Gendron, and Rousseau, 2016]; [Rocha, Oliveira, and Carravilla, 2013]; [Wan and Bard, 2007]
Production	**5**	
Assembly lines	1	[Bhatnagar, Saddikutti, and Rajgopalan, 2007]
Factory	1	[Hertz, Lahrichi, and Widmer, 2010]
General	2	[Akbari, Zandieh, and Dorri, 2013]; [Gérard, Clautiaux, and Sadykov, 2016]
Job shop	1	[Yang, Webster, and Ruben, 2007]
Transportation	**10**	
Airline catering	1	[Ho and Leung, 2010]
Autonomous robots	1	[Thangiah, Shmygelska, and Mennell, 2001]
Distribution	2	[Ho and Haugland, 2004]; [Li, Tian, and Leung, 2010]
General	3	[Lei, Laporte, and Guo, 2011]; [Salani and Vacca, 2011]; [Taş et al., 2014]
Postal service	2	[Laporte, Nobert, and Taillefer, 1987]; [Zäpfel and Bögl, 2008]
Waste collection	1	[Bruecker et al., 2018]
Service	**89**	
Accounting service	1	[M. Miranda, 2019]
Airfreight handling	1	[Rong and Grunow, 2009]
Ambulance service	1	[Zhang et al., 2017]
Baggage claim at airports	1	[Chu, 2007]
Call center	3	[Avramidis et al., 2010]; [Örmeci, Salman, and Yücel, 2014]; [Valls, Pérez, and Quintanilla, 2009];
Check-in at airports	2	[Stolletz and Zamorano, 2014]; [Stolletz, 2010]
Consulting	1	[Cavalcante, Cardonha, and Herrmann, 2013]
Education	1	[Sanchez-Anguix et al., 2019]
General	9	[Ağralı, Taşkın, and Ünal, 2017]; [Alfares, 1998]; [Bard, 2004]; [Bredström and Rönnqvist, 2008]; [Kim, Koo, and Park, 2010]; [Lim, Rodrigues, and Song, 2004]; [Pillac, Guéret, and Medaglia, 2013]; [Siquitelli, Romeiro, and Ribeiro, 2016]; [Topaloglu and Ozkarahan, 2004]
Home care	25	[Akjiratikarl, Yenradee, and Drake, 2007]; [Bachouch, Guinet, and Hajri-Gabouj, 2010]; [Bard et al. 2014]; [Bertels and Fahle, 2006]; [Borsani et al., 2017]; [Braekers et al., 2016]; [Cappanera et al., 2018]; [Cappanera and Scutellà, 2014]; [Decerle et al., 2018]; [Du, Liang, and Sun, 2017]; [Eveborn, Flisberg, and Rönnqvist, 2006]; [Grenouilleau et al., 2019]; [Jemai, Chaieb, and Mellouli, 2013]; [Liu, Yuan, and Jiang, 2018]; [Mankowska, Meisel, and Bierwirth, 2014]; [Moussavi, Mahdjoub, and Grunder, 2019]; [Nickel, Schröder, and Steeg, 2012]; [Restrepo, Rousseau, and Vallée, 2019]; [Shao, Bard, et Jarrah, 2012]; [Shi, Boudouh, and Grunder, 2019]; [Trautsamwieser and Hirsch, 2011]; [Yalçindağ et al., 2016]; [Yalçindağ, Matta, and Sahin, 2012]; [Yuan, Liu, and Jiang, 2015]; [Zhan and Wan, 2018];

Sectors	Nb of articles	Articles
Home care for offices	3	[Bard, Shao, and Jarrah, 2014]; [Nasir, Hussain, and Dang, 2018]; [Ogulata, Koyuncu, and Karakas, 2008]
Hospital care	18	[Beaulieu et al., 2000]; [Bester, Nieuwoudt, and Van Vuuren, 2007]; [Burke et al., 2010]; [Burke, Causmaecker, and Vanden Berghe, 2007]; [Carrasco, 2010]; [Carter and Lapierre, 2001]; [Constantino et al., 2011]; [Dias et al., 2003]; [Ferrand, 2011]; [Goodman, Dowsland, and Thompson, 2009]; [Jingpeng, Aickelin, and Burke, 2009]; [Kundu et al., 2008]; [Millar and Kiragu, 1998]; [Parr and Thompson, 2007]; [Rönnberg and Larsson, 2010]; [Rosenbloom and Goertzen, 1987]; [Sundari and Mardiyati, 2017]; [Topaloglu, 2006]
Maintenance service	18	[Alsheddy and Tsang, 2009]; [Borenstein et al., 2010]; [Cappanera, Gouveia, and Scutellà, 2013]; [Cappanera, Gouveia, and Scutellà, 2011]; [Chen, Thomas, and Hewitt, 2016]; [Cordeau et al., 2010]; [Firat and Hurkens, 2012]; [Firat, Briskor, and Laugier, 2016]; [Golden, Raghavan, and Wasil, 2008]; [Hashimoto et al., 2011]; [Kovacs et al., 2012]; [Lesaint, Voudouris, and Azarmi, 2000]; [López-Santana et al., 2016]; [Mehdi, Ebrahimnejad, and Safari, 2018]; [Su et al., 2019]; [Tang, Miller-Hooks, and Tomastik, 2007]; [Xu and Chiu, 2001]; [Zamorano and Stolletz, 2017]
Port worker	1	[Lim, Rodrigues, and Song, 2004]
Postal processing service	1	[Bard and Wan, 2007]
Retail outlets	2	[Parisio and Jones, 2015]; [Pastor and Olivella, 2008]
Training service	1	[Naderi and Kilic, 2016]

Table A.3. Number of articles by resolution method

Solution methods	**Number of articles**
Mathematical programming	**46**
Integer linear programming	16
Mixed integer linear programming	17
Goal programming	4
Column generation	2
Branch and price	6
Branch and bound	1
Heuristics	**14**
Greedy heuristic	1
Model enhancement heuristic	1
Optimization-based heuristic	1
Record-to-record travel heuristic	1
Repeated matching algorithm	1
Rolling planning horizon heuristic	1
Scheduling heuristic	1
Simulation-based heuristic	1
Two-stage stochastic programming	1
Two-step iterative approach	1
Other customized heuristics	4
Meta-heuristics	**60**
Ant Colony Optimization	1
Distributed Omni-Search	1
Evolutionary algorithm	3
Genetic algorithm	8
GRASP	4
Large neighborhood search	8
Local search	6
Matheuristic	2
Memetic algorithm	1
Particle swarm optimization	2
Simulated annealing	8
Tabu search	11
Variable neighborhood search	5
Solver package	**2**
Artificial intelligence methods	**2**
Simulation	**2**

Appendix B. Definitions of the four multi-objective MILP methods

B.1 Weighted-sum method (Yang, 2014)

The weighted sum method combines all the multi-objective functions into one scalar, composite objective function using the weighted sum

$$F(x) = w_1 f_1(x) + w_2 f_2(x) + ... + w_M f_M(x)$$

An issue arises in assigning the weighting coefficients $w = (w_1, w_2, ...w_M)$, because the solution strongly depends on the chosen weighting coefficients. Obviously, these weights have be positive, satisfying

$$\sum_{i=1}^{M} w_i = 1, w_i \in (0,1).$$

B.2 Weighted Tchebycheff method (Arora, 2012)

The weighted min-max method (also called the weighted Tchebycheff method) is formulated to minimize U, which is given as follows:

$$U = \max_i \{w_i [f_i(x) - f_i^o]\}$$

A common approach to treatment of equation above is to introduce an additional unknown parameter λ as follows:

Minimize λ

Subject to additional constraints

$$w_i [f_i(x) - f_i^o] - \lambda \leq 0$$

Whereas the weighted sum method always yields Pareto optimal points, but may miss certain points when the weights are varied, this method can provide all of the Pareto optimal points (the complete Pareto optimal set). However, it may provide non-Pareto optimal points as well. Nonetheless, the solution using the min-max approach is always weakly Pareto optimal, and if the solution is unique, then it is Pareto optimal.

B.3 ε-constraint method (Mavrotas, 2009)

Assume the following multi-objective mathematical programming problem:

$\max \ (f_1(x), f_2(x), \ldots, f_M(x))$

st

$x \in S$;

Where x is the vector of decision variables, $f_1(x), \ldots, f_M(x)$ are the M objective functions and S is the feasible region.

In the ε-constraint method we optimize one of the objective functions using the other objective functions as constraints, incorporating them in the constraint part of the model.

$\max f_1(x)$

st

$f_2(x) \geq e_2$,

$f_3(x) \geq e_3$,

. . .

$f_M(x) \geq e_M$,

$x \in S$.

By parametrical variation in the right-hand-side of the constrained objective functions (e_i) the efficient solutions of the problem are obtained.

B.4 Lexicographic method (Stanimirovic, 2012)

Here we restate the main idea of the lexicographic method. The objective functions are arranged in order of importance, either by the decision maker or by an algorithm. Then the sequence of single-objective optimization problems is solved, one problem at a time. It is assumed that the ordering of the objective functions is given by the sequence $\{Q_1(x) \dots Q_l(x)\}$. Then the stated problem is equivalent to the following sequence of single-objective programming problems, associated to the priority levels k, $k = 1,\dots,l$:

Maximize $F_k(x)$

Subject to: $F_j(x) \geq F_j(x_j^*)$, $j=1,\dots,(k-1)$, $k\geq 2$,

$x \in X$; $x_1\geq 0,\dots,x_n\geq 0$,

Where $F_j(x_j^*)$, $j = 1..(k-1)$; represent optimal values for the previously stated problems on the priority levels $j = 1..(k-1)$, $k\geq 2$.

Appendix C. Full data generation for the experiments of Chapter V

We use the original data benchmark provided by our Brazilian partner (see Section 4.3.2.1), which has 672 agents and 141 tasks, to generate a new data benchmark for the experiments of this chapter. However, the data needed for our experiments are not the same as those used in chapter 4. The tasks used for chapter 4 are weekly tasks characterized by task coverage types while those used for this chapter are daily tasks characterized by duration, time windows and required day. For agents, the total numbers of agents are the same in the two chapters. However, chapter 5 considers five additional agent characteristics in comparison to chapter 4 that include the last modulation counter, the preferences for work periods, the last workday and period, and the last day off in the previous planning horizon. Therefore, in order to create a new benchmark for this chapter, we need to generate the daily tasks from existing weekly tasks and the data for the five new agent characteristics.

In the original benchmark, we have 141 tasks belonging to 12 task coverage types (numbered from 1 to 12) (Table 10, Page. 64). Task coverage type 1 corresponds to the tasks required 5 consecutive days per week, 8 hours/day. Task coverage type 2 corresponds to the tasks required 6 consecutive days per week, and 8 hours/day. Task coverage types 3-8 correspond to the tasks required 7 days per week, and 8 hours per day. Task coverage types 9-12 correspond to the tasks required 7 days per week, and 24 hours per day. Because we decided to first consider only a low level demand variability, we keep the same daily task duration, and its start and end times as those of the original benchmark, and change only its daily repetitiveness over the week to generate daily tasks. For example, a weekly task with coverage type 1, requiring 5 consecutive days per week, can be split into 5 daily tasks of 5 consecutive days, possibly from day 1 to day 5, day 2 to day 6 or day 3 to day 7; the probabilities that these three cases are generated are assumed to be the same. Similarly, a task with coverage type 2, requiring 6 consecutive days per week, can be split into 6 daily tasks of 6 consecutive days, possibly from day 1 to day 6, or day 2 to day 7; the probabilities that these two cases are generated are assumed to be the same. A task with coverage types 3-12 is split into 7 daily tasks of 7 days from day 1 to day 7. By doing so, we generated 1343 daily tasks from 141 weekly tasks.

In terms of agent data, the last modulation counter is generated by a normal distribution whose expected value equals zero and standard deviation is 10% of the weekly contract time. This configuration ensures that 95% of the last modulation counters generated are within 20% of the weekly contract time.

The agents' preferences for certain work periods are generated as follows. Because shift agents (12x36, 8x24 and 4x20) usually have to perform tasks in different periods each day, they are assumed not to have a special preference for some work periods, PR_i^t get value zero for all the periods t. By contrast, non-shift agents, depending on their daily routine, prefer some work periods than others. We assume that these preferences fall into three categories: daylight agents (preferred periods: 2 and 3), early-evening agents (preferred periods 4-5), and night agents (preferred periods: period 6 of this day and period 1 of the day after) (see Section 5.2.2). We assume that the ratios between these categories (category 1: category 2: category 3) are 60%:20%:20%.

Because we assumed that the agent work plan in the previous horizon is the manually-made plan provided by our Brazilian partner. The agents' last workday, period, and the last day off can be extracted from this work plan. However, we assumed that 30% of the available agents is the newly recruited agents. The agents are recruited to replace former agents who left the company and to cover the demands of new clients. These new agents did not work in the previous horizon and therefore, did not have their last workday and period or last day off (given values 99).

Following the steps above, we generated the new benchmark from the original benchmark, which has 672 agents and 1343 tasks belonging to 66 clients. We use this benchmark to generate the instances for our experiments. For each instance, the numbers of clients, tasks, and agents are chosen between 3 and 6, 60 and 100, and 30 and 60 respectively. This number of clients between 3 and 6 is a typical number of clients of a district in the benchmark. Because our objective is to focus on the investigation of the problem characteristics, we use the territorial decomposition technique (district level), which is currently used by the company, to simplify the problem.. Using the territory decomposition corresponds to an approximation approach. This technique helps to divide a large service coverage regions into small zones (districts) and solve the problem inside each zone separately. We, therefore, obtain local optimal solutions in each zone instead of a global optimal solution for the whole coverage region. In order to generate an instance for our experiments, we randomly pick up a set of between 3 and 6 among the 66 available clients. Based on the manually-made plan provided by the company, we obtain the lists of tasks required by these clients and the agents assigned to these tasks. Choosing agents and tasks in this way can make sure that at least one feasible solution can be always obtained (see Figure C.1).

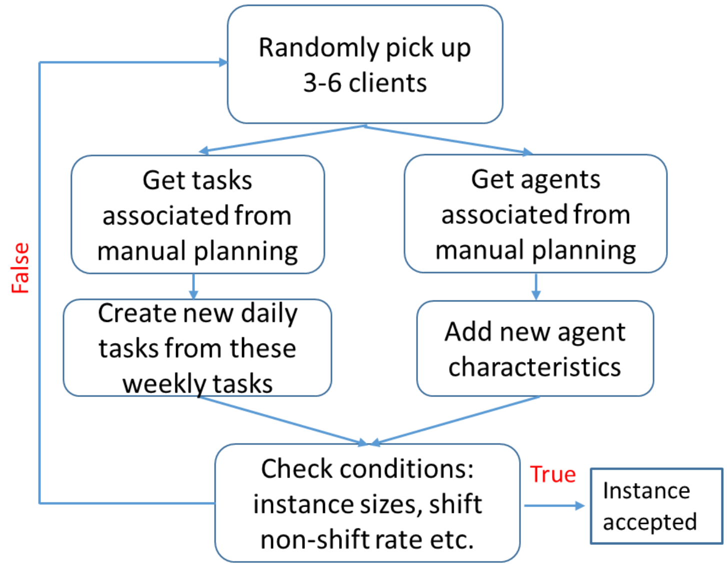

Figure C.1. The flowchart of instance generation

In order to have a balance between the number of shift and non-shift agents, the percentage of shift agents of 50% of the instances is chosen between 25% and 50% of the total number of agents, the remaining is the non-shift agent percentage; the percentage of shift agents of the other 50% of the instances is between 50% and 75%, the remaining is the non-shift agent percentage. Moreover, the proportion of the number of extra agents in comparison to the number of agents required by tasks is set to be 15%.

We consider 6 different scenarios in this experiment. The original scenario (scenario 0) corresponds to the current situation of the company where the agents are mono-skilled and only 4 work contracts are actually used. The instances of each of the other scenarios are not completely different from the original instances used for scenario 0. Depending on each specific scenario, only several characteristics are modified. Scenario 1 also uses only 4 work contracts but agents are considered multi-skilled. Scenario 2 considers only mono-skilled agents but two new contracts (8x24 and 4x20) are added. Scenario 3 considers both multi-skilled agents and using two new agent contracts. Scenario 4 and 5 also consider both multi-skilled agents and using two new agent contracts but in other contexts. Scenario 4 considers the “fully” dependent level while scenario 5 studies the problem in the case of dependent level with buffer zones (see Figure 13, page 110).

We generate 30 original instances for the experiments of scenario 0. In order to generate an instance of multi-skilled agents (scenario 1) from an original instance (scenario 0), we simply allow an agent to work in other workplaces besides his/her main workplace. However, an agent can only work in a workplace if it is less complex than his main workplace, for example, an agent working in a hospital can also work in shop or factory but the opposite is not allowed. In order to generate an instance of 6 agent contracts (scenario 2) from an original instance, we keep the number of non-shift contract agents (5x2, 6x1 and 5x1) fixed. Among the 12x36 agents, we keep a third of them, replace a third by 4x20 agents, and a remaining third by 8x24 agents. Because the average work capacity of the 12x36 agents is 42 hours/week while that of the 4x20 agents is 28 hours/week, we replace every two 12x36 agents by three 4x20 agents to ensure the total work capacity. The replacement ratio between the 12x36 and 8x24 contracts is 1:1 because these agents have the same average work capacity. Finally, in order to generate an instance of multi-skilled agents with 6 contract types from an original instance of mono-skilled agents with 4 contract types (scenario 3), we do both of the steps above. The instances used for scenarios 4 and 5 are the same as those of scenario 3, only some constraints of the MILP models are different between these three scenarios (see Section5.3.5.2, page 100).

In order to evaluate the impact of the two levers and three types of modeling the dependence between planning horizons through scenarios, we used only instances in which a feasible solution can be obtained in a certain calculation time for all the scenarios. However, scenario 4, corresponding to the consideration of the fully dependent between planning horizons, is quite constrained and a feasible solution cannot be often obtained in a limited calculation time. We use only instances in which a feasible solution can be obtained for all the scenarios, different from scenario 4.

To obtain instances for experiments, we first run a test of feasibility of 10 minutes for each instance generated by the instance generation process (Figure C.1). The instance is only kept for further experiments if the resolution method applied to it is not infeasible within 10 minutes for all the scenarios, different from scenario 4. Then, the real experiments are performed on these instances to investigate the feasibility of the problem solving with a longer calculation time of 10 hours. We found that among the instances which passed the feasibility test of 10 minutes, only 30% of them give a feasible solution in 10h of calculation time. In order to generate 30 instances for the in-depth experiments, we need to run the MILP model for about 100 instances.

Here are the characteristics for the 30 final instances used for our in-depth experiments. Because the number of agents of each contract is different between scenarios. Scenarios 0 and 1 consider only 4 current contracts (without 8x24 or 4x20), the other scenarios consider all six contracts. We choose to present, in Table C.1the characteristics for the 30 final instances of scenario 3, corresponding to the six agent contracts.

Table C.1. Characteristics of the 30 instances used for our experiments (scenario 3)

Indicator /Characteristic	Average	Min	Max	Median
Number of clients	4.5	3	6	4
Number of tasks	84.2	71	95	88
Number of agents	47.2	37	60	45
Number of agents 12x36	7.6	4	12	5
Number of agents 8x24	7.3	4	12	5
Number of agents 4x20	11.3	5	19	7
Number of agents 5x2	6.6	0	14	11
Number of agents 6x1	12.5	7	19	13
Number of agents 5x1	1.9	0	6	1
Shift / non-shift rate	57%:43%	33%:67%	73%:27%	37%:63%

Appendix D.
Full integer linear programming model of Chapter V

The presentation of our MILP model consists of indices, parameters, variables, objectives, and constraints.

D.1 Indices

- Days of the planning horizon: {1,..,d,.. D} (D=7)
- Periods of a day: {1,..,t,..T} (T=6)
- Agents: {1,..i,..N}
- Clients: {1,..,p,.. P}
- Tasks: {1,..,j,.. J}
- Skill types: {1,..,k,..,K}
- Skill levels: {1,..,q,..,Q}

D.2 Parameters

- TCL_{jp} : Task j belongs to client p, =1 if yes, =0, otherwise, $\forall j = 1..J, \forall p = 1..P$
- TDA_j^d : Task j is required on day d, =1 if yes, =0, otherwise, $\forall j = 1..J, \forall p = 1..P$
- TD_j : Duration of task j, $\in \{1,2,..T\}$, $\forall j = 1..J$
- STW_j : Start time of task j, $\in \{1,2,..T\}$, $\forall j = 1..J$
- ETW_j : End time of task j, $\in \{1,2,..T\}$, $\forall j = 1..J$
- NBA_{jkq} : Number of agents having skill type k level q required by task j, $\in \{1,2,\ldots\}$ $\forall j = 1..J, \forall k = 1..K, \forall q = 1..Q$
- NB_j : Total number of agents required by task j, $NB_j = \sum_{k=1}^{K}\sum_{q=1}^{Q} NBA_{jkq}$, $\forall j = 1..J$

- SA_{ikq}: Agent i has skill type k level q, =1 if yes, =0 otherwise, $\forall i = 1..N, \forall k = 1..K, \forall q = 1..Q$
- CT_i : Contract type of agent i (see Table 16, column 1), $\in \{1,2,..6\}$, $\forall i = 1..N$
- $MWTD_i$: Daily work time of agent i if he is active on that day (in number of periods), $\in \{1,2,..T\}, \forall i = 1..N$
- WWT_i : Weekly contractual work time of agent i (see Table 16, column 4), $\in \{1,2,..T\}$, $\forall i = 1..N$
- WTT_i : Weekly estimated travel time of agent i (see Table 16, column 5), $\in \{1,2,\ldots\}$, $\forall i = 1..N$
- CTA_{ij} : Compatibility between the duration of task j and the contract type of agent i, =1 if compatible, =0 otherwise, $\forall i = 1..N, \forall j = 1..J$ (Cf. Table 18)
- IC_i : Last modulation counter of agent i at the beginning of the planning horizon: $\forall i = 1..N$
- PR_i^t: Preference of agent i for period t, = -1: dislike, =0: neutral, =1: like, $\forall i = 1..N, \forall t = 1..T$
- LD_i : The last workday of agent i in the previous planning horizon, $LD_i \in \{1, 2, ..7\} \cup \{99)$, $LD_i = 99$ if agent i did not work any day in the previous planning horizon
- LS_i : The last work period of the last workday of agent i in the previous planning horizon, $LS_i \in \{1, 2, ..6\} \cup \{99\}$, $LS_i = 99$ if agent i did not work any day in the previous planning horizon
- LDO_i : The last day off in the previous planning horizon of agent i, $LDO_i \in \{1, 2, ...\}$, $LDO_i = 99$ if agent i did not work any day in the previous planning horizon
- TC_{ip} : Travel cost from agent site i to client site p, $\forall j = 1..J, \forall p = 1..P$
- TT_{ip} : Travel time from agent site i to client site p, $\forall j = 1..J, \forall p = 1..P$

- ICP_{ip} : Incompatibility between agent i and client p, =1 if incompatible, =0, otherwise, i=1..N, p=1..P

D.3 Variables

- x_{ij}^{t} : =1 if agent i performs task j at period t, =0 otherwise, $\forall i=1..N, \forall j=1..J, \forall t=1..T$
- y_{ij} : =1 if agent i performs task j, =0 otherwise, $\forall i=1..N, \forall j=1..J$
- z_{i}^{dt} : =1 if agent i works at period t of day d, =0 otherwise, $\forall i=1..N, \forall d=1..D, \forall t=1..T$
- w_{i}^{d} : =1 if agent i works on day d, =0 otherwise, $\forall i=1..N, \forall d=1..D$
- u_i : =1 if agent i works, =0, otherwise, $\forall i=1..N$
- v_i : Real work time of agent i during the planning horizon, i.e. his travel time, $\forall i=1..N$
- mmc : Maximum absolute value of agents'modulation counters
- b_{i}^{dt} : =1 if agent i of 12x36 contract works between periods t and t+2 of day d, =0 otherwise, $\forall i=1..N, \forall d=1..D, \forall t=1..(T-2)$
- c_{i}^{dt} : =1 if agent i who has a work contract type 2/4/5/6 works between periods t and t+1 of day d, =0 otherwise, $\forall i=1..N, \forall d=1..D, \forall t=1..(T-1)$

D.4 Objectives

In this model, we consider three objectives. The first objective is the minimization of the total travel costs between agent homes and their workplaces (2). The second objective is the maximization of the workload balance between agents in the same planning horizon and between planning horizons of each agent that can be obtained by minimizing the maximum absolute value of their modulation counters (3). The last objective is the maximization of agents' preferences for assigned work periods (4). These three objectives are aggregated in a weighted sum objective function (1).

Minimize: $\alpha\Pi_{TC} + \beta\Pi_{MC} - \gamma\Pi_{PR}$ (1)

- $$\Pi_{TC} = \sum_{i=1}^{N}\sum_{j=1}^{J}\sum_{p=1}^{P}(2 \times TC_{ip} \times TCL_{jp} \times y_{ij}) \quad (2)$$

- $$\Pi_{MC} = mmc \quad (3)$$

- $$\Pi_{PR} = \sum_{i=1}^{N}\sum_{d=1}^{D}\sum_{t=1}^{T} PR_i^t \times z_i^{dt} \quad (4)$$

D.5 Constraints

The constraints are divided into two groups that include the common constraints, which are shared by the three types of modeling the dependence between planning horizons, and the private constraints of each of these three types.

D.5.1 Common constraints

- $$\sum_{i=1}^{N} SA_{ikq} \times x_{ij}^t \geq NBA_{jkq}, \forall j = 1..J, \forall k = 1..K, \forall q = 1..Q, \forall t = STW_j..ETW_j \quad (5)$$

- $$\sum_{i=1}^{N} x_{ij}^t = NB_j, \forall j = 1..J, \forall t = STW_j..ETW_j \quad (6)$$

- $$x_{ij}^t = 0, \forall i = 1..N, \forall j = 1..J, \forall t = 1..T \,/\, t < STW_j \text{ or } t > ETW_j \quad (7)$$

Constraints (5) and (6) ensure that for each skill type and skill level, the number of agents assigned to a task at each period within its time windows $[STW_j, ETW_j]$ has to equal the number of agents required. Constraints (5) use inequalities instead of equalities because some agents may have a skill level for some skill types that are not exploited by the task (multi-skilled agents). These inequalities still allow the number of agents of each skill type and skill level assigned to a task to be greater than the number of agents it actually requires. Constraints (6) are added to ensure that these numbers are equal globally. Constraints (7) make sure that no agent is assigned to a task at any period outside of its time windows.

- $y_{ij} \leq CTA_{ij}, \forall i = 1..N, \forall j = 1..J$ (8)

- $\sum_{j=1}^{J} TDA_j^d \times y_{ij} = w_i^d, \forall i = 1..N, \forall d = 1..D$ (9)

Constraints (8) ensure the compatibility between a task duration and an agent contract type (see Table 18). An agent can only be assigned to a task whose duration is greater than or equal to his/her daily work capacity. Constraints (9) ensure that each agent is assigned to a maximum one task per day.

- $\sum_{t=1}^{T} x_{ij}^t = MWTD_i \times y_{ij}, \forall i = 1..N / CT_i \in \{1,2,4,5,6\}, \forall j = 1..J$ (10)

- $y_{ij} \leq \sum_{t=1}^{T} x_{ij}^t \leq 3 \times y_{ij}, \forall i = 1..N / CT_i = 3, \forall j = 1..J$ (11)

- $\sum_{j=1}^{J} TDA_j^d \times x_{ij}^t = z_i^{dt}, \forall i = 1..N, \forall d = 1..D, \forall t = 1..T$ (12)

- $\sum_{t=1}^{T} z_i^{dt} = MWTD_i \times w_i^d, \forall i = 1..N / CT_i \in \{1,2,4,5,6\}, \forall d = 1..D$ (13)

- $w_i^d \leq \sum_{t=1}^{T} z_i^{dt} \leq 3 \times w_i^d, \forall i = 1..N / CT_i = 3, \forall d = 1..D$ (14)

- $u_i \leq \sum_{d=1}^{D} w_i^d \leq D \times u_i, \forall i = 1..N$ (15)

Constraints (10)-(15) show the relations between the problem variables. Because an agent (with a contract type different from 4x20) is assumed to perform a maximum of one task per day, constraints (10) are used to ensure that if this agent performs a task, he/she has to work with his/her daily capacity $MWTD_i$. Constraints (11) imply that an agent with contract 4x20 can perform a task with at most his/her maximum daily capacity of 3 periods (12h). However, he/she can perform a task whose size is greater than 12 hours by working together with another agent. Constraints (12) ensure that an agent works in a particular period of a day if he/she performs a task in that period of that day. Constraints (13) imply that if an agent (with a contract type different from 4x20) works on a day, he/she has to work at his/her daily capacity $MWTD_i$. Constraints (14) ensure that an agent with contract 4x20 cannot exceed his/her maximum daily capacity of 3 periods (12h). Constraints (15) make sure that an agent works during the planning horizon if he/she works on at least one of its days.

- $$\sum_{t=1}^{T-2} b_i^{dt} \le 1, \ \forall i / CT_i = 1, \forall d = 1..D \quad (16)$$

- $$\begin{cases} z_i^{dt} = b_i^{d(t-2)} + b_i^{d(t-1)} + b_i^{dt}, \forall t = 3..4 \\ z_i^{d5} = b_i^{d3} + b_i^{d4} \\ z_i^{d6} = b_i^{d4} \\ z_i^{d2} = b_i^{d1} + b_i^{d2} \\ z_i^{d1} = b_i^{d1} \end{cases} , \forall i / CT_i = 1, \ \forall d = 1..D, \quad (17)$$

- $$\sum_{t=1}^{T-1} c_i^{dt} \le 1, \ \forall i / CT_i \in \{2,4,5,6\}, \ \forall d = 1..D \quad (18)$$

- $$\begin{cases} z_i^{dt} = c_i^{d(t-1)} + c_i^{dt}, \forall t = 2..5 \\ z_i^{d1} = c_i^{d1} \\ z_i^{d6} = c_i^{d5} \end{cases} , \forall i / CT_i \in \{2,4,5,6\}, \ \forall d = 1..D \quad (19)$$

- $$\begin{cases} z_i^{d1} + z_i^{dt} \le u_i, \forall t = 4..6 \\ z_i^{d2} + z_i^{dt} \le u_i, \forall t = 5..6 \\ z_i^{d3} + z_i^{d6} \le u_i \end{cases} , \ \forall i / CT_i = 3, \ \forall d = 1..D \quad (20)$$

- $$z_i^{dt} + z_i^{d(t+2)} - z_i^{d(t+1)} \le u_i, \forall t = 1..4, \forall i / CT_i = 3, \ \forall d = 1..D \quad (21)$$

Constraints (16) and (17) ensure the continuity of the work periods of agents with shift contract 12x36. An agent with this contract type can perform tasks only between periods 1 and 3, 2 and 4, 3 and 5, or 4 and 6. Similarly, constraints (18) and (19) ensure the continuity of the work periods of agents with shift contract 8x24 and non-shift contracts; an agent with this contract type can perform tasks only between periods 1 and 2, 2 and 3, 3 and 4, 4 and 5, or 5 and 6. Constraints

(20) and (21) ensure the continuity of the work periods of agents with shift contract 4x20, if an agent with this contract works 2 or 3 periods on a day, these periods have to be consecutive.

Contract types 4, 5, and 6

- $$\begin{cases} z_i^{dt} - z_i^{d_1t} \le 2 - (w_i^d + w_i^{d_1}) \\ z_i^{dt} - z_i^{d_1t} \ge w_i^d + w_i^{d_1} - 2 \end{cases}, \forall d = 1..D, \forall d_1 = (d+1)..D, \forall i / CT_i \in \{4,5,6\} \quad (22)$$

Constraints (22) ensure that if a non-shift agent (contract types 4, 5 or 6) works in a particular period of a day, he/she has to work in the same period on the other days of the week (except for his/her days off).

- $$v_i = 4 \times \sum_{d=1}^{D} \sum_{t=1}^{T} z_i^{dt} + 2 \times \sum_{j=1}^{J} \sum_{p=1}^{P} TT_{ip} \times TCL_{jp} \times y_{ij}, \forall i = 1..N \quad (23)$$

- $$mmc \ge v_i - (WWT_i + WTT_i) \times u_i + IC_i, \forall i = 1..N \quad (24a)$$

- $$mmc \ge -[v_i - (WWT_i + WTT_i) \times u_i + IC_i], \forall i = 1..N \quad (24b)$$

Constraints (23) refer to the total real work time of an agent during the planning horizon, including his/her travel time. Constraints (24a) and (24b) define the maximum absolute value of agents' modulation counters.

D.5.2 Private constraints of three types of dependence

We consider one by one the private constraints of three ways to model the dependence between planning horizons that include the independent, the "fully" dependent and the dependent with buffer zones.

Independent

- $$z_i^{dt} = z_i^{(d+2)t}, \forall i = 1..N / CT_i = 1, \forall d = 1..(D-2), \forall t = 1..T \quad (25A)$$

- $$\sum_{d_1=d}^{d+1} \sum_{t=1}^{T} z_i^{d_1t} = 3 \times u_i, \forall i = 1..N / CT_i = 1, \forall d = 1..(D-1) \quad (26A)$$

- $$z_i^{dt} = z_i^{(d+1)(t+2)}, \forall i = 1..N / CT_i = 2, \forall d = 1..(D-1), \forall t = 1..(T-2) \quad (27A)$$

- $z_i^{dt} = z_i^{(d+2)(t-T+2)}, \forall i = 1..N / CT_i = 2, \forall d = 1..(D-2), \forall t = (T-1)..T$ (28A)

- $\sum_{d_1=d}^{d+3} \sum_{t=1}^{T} z_i^{d_1 t} = 6 \times u_i, \forall i = 1..N / CT_i = 2, \forall d = 1..(D-3)$ (29A)

Constraints (25A) and (26A) are applied to agents with contract 12x36. Constraints (25A) imply that if an agent works in period t, on day d, he/she also has to work in the same period 2 days later. Constraints (26A) ensure that if an agent with this contract type is used, he/she has to work exactly 3 periods of 4 hours for any 2 consecutive days. Similarly, constraints (27A), (28A) and (29A) are applied to agents with contract type 2. Constraints (27A) imply that if an agent works in period t (t≤T-2), on day d, he/she also has to work in period t+2, 1 day later. Constraints (28A) ensure that if an agent works in periods T-1 or T, on day d, he/she also has to work in period 1 or 2, 2 days later. Constraints (29A) ensure that if an agent with this contract type is used, he/she has to work 6 periods of 4 hours for any 4 consecutive days.

- $6 \times u_i \le \sum_{d=1}^{D} \sum_{t=1}^{T} z_i^{dt} \le 8 \times u_i, \forall i = 1..N / CT_i = 3$ (30A)

- $\sum_{t_1=t}^{T} z_i^{dt_1} + \sum_{t_2=1}^{t-T+3} z_i^{(d+1)t_2} \le 1, \forall i = 1..N / CT_i = 3, \forall d = 1..(D-1), \forall t = (T-2)..T$ (31A)

Constraints (30A) and (31A) are applied to agents with contract 4x20. Constraints (30A) imply that each agent with contract 4x20 has to work between 6 and 8 periods of 4 hours per week. Constraints (31A) ensure the minimum time lag between two consecutive work periods (no more than one work period for any duration of 16 hours).

- $\begin{cases} w_i^2 + w_i^7 = u_i \\ w_i^1 + w_i^6 = u_i \\ w_i^1 + w_i^7 \le u_i \\ w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N / CT_i = 4$ (32A)

- $$\begin{cases} w_i^1 + w_i^7 = u_i \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = w_i^6 = u_i \end{cases}, \forall i = 1..N / CT_i = 5 \qquad (33A)$$

- $$\begin{cases} w_i^1 + w_i^6 = u_i \\ w_i^1 = w_i^7 \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (34A)$$

Agents with contract 5x2 have to work 5 consecutive days during the week that can be from day 1 to day 5, day 2 to day 6, or day 3 to day 7. In any of these three cases, these agents have to work on days 3, 4 and 5 (the last equations of constraints (32A)). The other two days can be chosen between days 1 and 2, days 2 and 6, or days 6 and 7 (the first three equations of constraints (32A)). Agents with contract 6x1 have to work 6 consecutive days during the week that can be from day 1 to day 6, or day 2 to day 7. In any of these two cases, these agents have to work from day 2 to day 6. The other day can be chosen between day 1 and day 7 (33A). Agents with contract 6x1 have to work 5 consecutive days and have a break of 1 day for any duration of 6 days. Five consecutive days can be from day 1 to day 5, or day 2 to day 6. So, they can work 6 days during the week, taking day 6 off, or 5 days from day 2 to day 6, taking both days 1 and 7 off. In any of these two cases, these agents have to work on days 2, 3, 4 and 5 (the last equations of constraints (34A)). The other workdays can be day 6 or days 1 and 7 (the first two equations of constraints (34A))

<u>"Fully" dependent</u>

In the case of "fully" dependent and dependent with buffer zones, we use the three parameters LD_i, LS_i, and LDO_i that correspond the last workday, period and the last day off of the agent in the previous horizon to explain the constraints used. These three parameters are used to model the links between the last agents' activity in the previous horizon and his first activity on this horizon. For further information, see Section 5.3.2 –Parameters.

Contract 12x36

Agents with contract 12x36 always have to work 12 hours for any duration of 2 days, so their last workdays can only be day 6 or 7. On the other hand, agents with this contract type are assumed to be assigned to 3 consecutive periods, their last work period can, therefore, be periods 3, 4, 5 or

6. Based on their last work period and workday in the previous planning horizon, we can calculate their first work period and workday of the current planning horizon (Table D.1).

Table D.1. Relations between the first work period and workday of the 12x36 agents in the previous and the current planning horizons

LD_i / LS_i	3	4	5	6
6	Period 1 day 1	Period 2 day 1	Period 3 day 1	Period 4 day 1
7	Period 1 day 2	Period 2 day 2	Period 3 day 2	Period 4 day 2

Constraints (25A) and (26A) of scenario 1 are also applied to this scenario. We moreover have additional constraints, depending on each specific situation.

If LD_i = 99: no additional constraints needed

If LD_i =6 or LD_i =7: we have additional constraints (25B)

- $z_i^{(LD_i-D+2)(LS_i-2)} = u_i, \forall i = 1..N / CT_i = 1$ (25B)

Constraints (25B) ensure the dependence between the last work period and the last workday of an agent with contract 12x36 in the previous planning horizon and those in the current planning horizon (presented in Table D.1).

Contract 8x24

Because an agent with contract 8x24 always has to work 8 hours for any duration of one day and 8 hours, their last workday can only be day 6 or 7. Moreover, these two periods have to be consecutive, their last work period can only be 2, 3, 4, 5 or 6. Based on their last work period and workday, we can calculate their first work period and workday in the current planning horizon (see Table D.2).

Table D.2. Relations between the first work period and workday of agents with contract 8x24 in the previous and current planning horizons

LD_i / LS_i	2	3	4	5	6
6	-	-	-	-	Period 1 day 1
7	Period 3 day 1	Period 4 day 1	Period 5 day 1	Period 6 day 1	Period 1 day 2

Constraints (27A), (28A), and (29A) are also applied to this scenario. Additional constraints are as follows:

If LD_i = 99: No additional constraints needed

If LD_i=6 or LD_i=7, and LS_i=6: additional constraints (26B) are applied.

- $z_i^{(LD_i-D+2)1} = 1 \times u_i, \forall i = 1..N / CT_i = 2$ (26B)

If LD_i=7, $LS_i \leq 5$: additional constraints (27B) are applied:

- $z_i^{1(LS_i+1)} = 1 \times u_i, \forall i = 1..N / CT_i = 2$ (27B)

Constraints (26B) and (27B) ensure the dependence between the last work period and the last workday of an agent with contract 8x24 in the previous planning horizon and those in the current planning horizon (see Table D.2).

Contract 4x20

Constraints (30A) and (31A) are also applied to this scenario. Additional constraints are as follows:

If $LD_i \neq 7$ or $LD_i = 7$ and $LS_i \leq 3$: no additional constraints needed

If LD_i =7 and $LS_i \geq 4$: we have additional constraints (28B). These constraints ensure the minimum time lag between the last work period of day 7 in the previous planning horizon and the first work period of day 1 in the current planning horizon.

- $\sum_{t=1}^{LS_i-T+3} z_i^{1t} = 0, \forall i = 1..N / CT_i = 3$ (28B)

Contract 5x2

For agents with the 5x2 contract type, the last day off in the previous planning horizon cannot be the first day (LDO_i >1), because if an agent takes day 1 off, he/she has to take day 7 off as well. The last day off is, therefore, day 7, not day 1.

Because 2 days off of an agent in a planning horizon are consecutive (except day 1 and day 7), if we know the last day off (excepting day 7) of an agent in the previous planning horizon, we can know their two days off, and thus we can also know their 2 days off in the current planning horizon (Table D.3). If the last day off is 7, the last two days off can be days 6 and 7, or days 1 and 7. So, in order to distinguish between these two cases, we set $LDO_i = 7$ if the two days off are days 6 and 7, and $LDO_i = 8$ for the second case.

Table D.3. Relations between the last day off of the previous planning horizon and the two days off of the current planning horizon for agent with contract type 5x2

LDO_i	2	3	4	5	6	7	8
2 days off of the current horizon	1 and 2	2 and 3	3 and 4	4 and 5	5 and 6	6 and 7	7 and 1

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$: Constraints (32A) are applied.

If $2 \le LDO_i \le 7$: Constraints (29B) and (30B) are applied

- $$w_i^{LDO_i - 1} + w_i^{LDO_i} = 0, \forall i = 1..N / CT_i = 4 \quad (29B)$$
- $$\sum_{d=1}^{D} w_i^d = 5 \times u_i, \forall i = 1..N / CT_i = 4 \quad (30B)$$

Constraints (29B) imply that the two days off of the current horizon are LDO_i-1 and LDO_i, while constraints (30B) ensure that if a 5x2 agent works during the planning horizon, his/her number of workdays has to equal 5.

If $LDO_i = 8$: Constraints (30B) are also applied. Additional constraints (31B) ensure that the two days off have to be days 1 and 7.

- $$w_i^1 = w_i^7 = 0, \forall i = 1..N / CT_i = 4 \quad (31B)$$

Contract 6x1

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$: Constraints (33A) of scenario 1 are applied.

If $1 \le LDO_i \le 7$: Constraints (32B) and (33B) are applied. Constraints (32B) imply that the day off in the current planning horizon is also the day off in the previous planning horizon. Constraints (33B) imply that if a 6x1 agent works in a planning horizon, his/her number of workdays has to equal 6.

- $w_i^{LDO_i} = 0, \forall i = 1..N / CT_i = 5$ (32B)

- $\sum_{d=1}^{D} w_i^d = 6 \times u_i, \forall i = 1..N / CT_i = 5$ (33B)

Contract 5x1

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$: Constraints (34A) are applied.

If $2 \le LDO_i \le 7$: Constraints (34B) and (35B) are applied

- $w_i^{LDO_i - 1} = 0, \forall i = 1..N / CT_i = 6$ (34B)

- $\begin{cases} \sum_{d=1}^{D-1} w_i^d = 5 \times u_i \\ w_i^7 = w_i^1 \end{cases}, \forall i = 1..N / CT_i = 6$ (35B)

Constraints (34B) imply that the day off of the current planning horizon is the day before the day off of the previous planning horizon. Constraints (35B) ensure that if a 5x1 agent works during a planning horizon, his/her workdays can be 5 days from day 2 to day 6 or 6 days with a day-off chosen between days from day 2 to day 6.

<u>Dependent with buffer zones</u>

Contract 12x36

Table D.4. Relations between the last workday and period in the previous horizon and the possibly earliest workday and period on the current horizon for agents with contract 12x36

LD_i / LS_i	3	4	5	6
6	Period 1 day 1	Period 2 day 1	Period 3 day 1	Period 4 day 1
7	Period 1 day 2	Period 2 day 2	Period 3 day 2	Period 4 day 2

If $LD_i = 99$: Constraints (25C)-(33C) are applied. Constraints (25C)-(29C) ensure that periods between two consecutive shifts of 3 work periods are break time (non-work time). Constraints (30C) and (31C) ensure that an agent with 12x36 contract works at most 1 shift of 12 hours for any duration of 48h. Constraints (32C) and (33C) ensure that an agent with this contract works at least 1 shift of 12 hours for any duration of 60h.

- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=t_1+3}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=2..3,\forall d_1=1..5,\forall t_2=t_1..4 \qquad (25C)$$

- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=t_1+3}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=1,\forall d_1=1..5,\forall t_2=2..4 \qquad (26C)$$

- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=t_1+3}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=1,\forall d_1=1..5,\forall t_2=1 \qquad (27C)$$

- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+2)t_2})\geq\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t},$$
  $$\forall i=1..N/CT_i=1,\forall t_1=4,\forall d_1=1..5,\forall t_2=4 \qquad (28C)$$

- $$12\times(2-b_i^{d_1t_1}-b_i^{(d_1+3)t_2})\geq\sum_{t=1}^{T}(z_i^{(d_1+1)t}+z_i^{(d_1+2)t}),$$
  $$\forall i=1..N/CT_i=1,\forall t_1=4,\forall d_1=1..4,\forall t_2=1 \qquad (29C)$$

- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_1=1}^{T}z_i^{(d+1)t_1}+\sum_{t_1=1}^{t-1}z_i^{(d+2)t_1}\leq u_i,\ \forall i=1..N/CT_i=1,\forall t=2..T,\forall d=1..5 \qquad (30C)$$

- $$\sum_{t_1=1}^{T}z_i^{dt_1}+\sum_{t_1=1}^{T}z_i^{(d+1)t_1}\leq u_i,\ \forall i=1..N/CT_i=1,\forall t=1,\forall d=1..6 \qquad (31C)$$

- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_1=1}^{T}z_i^{(d+1)t_1}+\sum_{t_1=1}^{t+2}z_i^{(d+2)t_1}\geq u_i,\ \forall i=1..N/CT_i=1,\forall t=1..4,\forall d=1..5 \qquad (32C)$$

- $$\sum_{t_1=t}^{T} z_i^{dt_1} + \sum_{t_1=1}^{T} z_i^{(d+1)t_1} + \sum_{t_1=1}^{T} z_i^{(d+2)t_1} + \sum_{t_1=1}^{t-4} z_i^{(d+3)t_1} \geq u_i\,, \forall i = 1..N / CT_i = 1, \forall t = 5..6, \forall d = 1..4$$

(33C)

If LD_i = 6/7 and LS_i = 3/4/5/6: Besides constraints (25C)-(33C), we have moreover additional constraints (34C) and (35C). These constraints ensure the break time at the beginning of the current horizon for the agents who work at the end of the previous horizon.

- $z_i^{dt} = 0\,,\ \forall i = 1..N / CT_i = 1, \forall d = 1..D / d = LD_i - 6, \forall t = 1..T$ (34C)

- $z_i^{dt} = 0\,,\ \forall i = 1..N / CT_i = 1, \forall d = 1..D / d = LD_i - 5, \forall t = 1..T / t \leq LS_i - 3$ (35C)

Contract 8x24

Table D.5. Relations between the last workday and period on the previous horizon and the possibly earliest workday and period on this horizon for agents with contract 8x24

LD_i / LS_i	2	3	4	5	6
6	-	-	-	-	Period 1 day 1
7	Period 3 day 1	Period 4 day 1	Period 5 day 1	Period 6 day 1	Period 1 day 2

If LD_i = 6 or LD_i = 99: Constraints (36C)-(44C) are applied. Constraints (36C)-(40C) ensure that periods between two consecutive shifts of 2 work periods are break time (non-work time). Constraints (41C) and (42C) ensure that an agent with 8x24 contract works at most 1 shift of 8 hours for any duration of 32h. Similarly, constraints (43C) and (44C) ensure that an agent with 8x24 contract works at least 1 shift of 8 hours for any duration of 40h.

- $$8 \times (2 - c_i^{d_1 t_1} - c_i^{(d_1+1)t_2}) \geq \sum_{t=t_1+2}^{T} z_i^{d_1 t} + \sum_{t=1}^{t_2-1} z_i^{(d_1+1)t}\,,$$

  $\forall i = 1..N / CT_i = 2, \forall t_1 = 1..3, \forall t_2 = (2 + t_1)..5, \forall d_1 = 1..6$ (36C)

- $$8 \times (2 - c_i^{d_1 t_1} - c_i^{(d_1+2)t_2}) \geq \sum_{t=t_1+2}^{T} z_i^{d_1 t} + \sum_{t=1}^{T} z_i^{(d_1+1)t} + \sum_{t=1}^{t_2-1} z_i^{(d_1+2)t}\,,$$

  $\forall i = 1..N / CT_i = 2, \forall t_1 = 4, \forall t_2 = 2..(t_1 - 2), \forall d_1 = 1..5$ (37C)

- $$8\times(2-c_i^{d_1t_1}-c_i^{(d_1+2)t_2})\geq\sum_{t=1}^{T}z_i^{(d_1+1)t}+\sum_{t=1}^{t_2-1}z_i^{(d_1+2)t}\,,$$
$$\forall i=1..N/CT_i=2,\forall t_1=5,\forall t_2=2..(t_1-2),\forall d_1=1..5 \qquad (38C)$$
$$8\times(2-c_i^{d_1t_1}-c_i^{(d_1+2)t_2})\geq\sum_{t=t_1+2}^{T}z_i^{d_1t}+\sum_{t=1}^{T}z_i^{(d_1+1)t}\,,$$
$$\forall i=1..N/CT_i=2,\forall t_1=3..4,\forall t_2=1,\forall d_1=1..5 \qquad (39C)$$

- $$8\times(2-c_i^{d_1t_1}-c_i^{(d_1+2)t_2})\geq\sum_{t=1}^{T}z_i^{(d_1+1)t}\,,\ \forall i=1..N/CT_i=2,\forall t_1=5,\forall t_2=1,\forall d_1=1..5 \qquad (40C)$$

- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_2=1}^{1+t}z_i^{(d+1)t_2}\leq 2\times u_i\,,\ \forall i=1..N/CT_i=2,\forall t=1..5,\forall d=1..6 \qquad (41C)$$

- $$z_i^{d6}+\sum_{t=1}^{T}z_i^{(d+1)t}+z_i^{(d+2)1}\leq 2\times u_i\,,\ \forall i=1..N/CT_i=2,\forall d=1..5 \qquad (42C)$$

- $$\sum_{t_1=t}^{T}z_i^{dt_1}+\sum_{t_2=1}^{3+t}z_i^{(d+1)t_2}\geq 2\times u_i\,,\ \forall i=1..N/CT_i=2,\forall t=1..3,\forall d=1..6 \qquad (43C)$$

- $$\sum_{t_1=t+3}^{T}z_i^{dt_1}+\sum_{t_2=1}^{T}z_i^{(d+1)t_2}+\sum_{t_3=1}^{t}z_i^{(d+1)t_3}\geq 2\times u_i\,,\ \forall i=1..N/CT_i=2,\forall t=1..3,\forall d=1..5 \qquad (44C)$$

If LD_i = 7 and LS_i = 2/3/4/5/6: Beside constraints (36C)-(44C), we have moreover additional constraints (45C). Constraints (45C) imply that no agent with 8x24 contract can perform tasks before the end of their break time at the end of the previous planning horizon and at the beginning of this planning horizon.

- $$z_i^{1t}=0\,,\ \forall i=1..N/CT_i=1,\forall t\leq LS_i \qquad (45C)$$

Contract 4x20

Constraints (30A) and (31A) are also applied to the case of dependent with buffer zones. Additional constraints are as follows:

If $LD_i \neq 7$ or $LD_i = 7$ and $LS_i \leq 3$: no additional constraints needed

If $LD_i = 7$ and $LS_i \geq 4$: we have additional constraints (46C). These constraints ensure the minimum time lag between the last work period of day 7 in the previous planning horizon and the first work period of day 1 in the current planning horizon.

- $$\sum_{t=1}^{LS_i - T + 3} z_i^{1t} = 0, \forall i = 1..N / CT_i = 3 \qquad (46C)$$

Contract 5x2

Because the number of days off between two consecutive sets of five workdays can vary between two and four, knowing only the last day off of an agent in the previous planning horizon is not enough to determine their days off in this planning horizon. When the last day-off is day 7, the other days off can be day 6, day 1, days 6 and 5, or days 6, 5, and 4. We use four values of LDO_i (7, 8, 9 and 10) to represent these four possibilities.

Table D.6. Relations between the last day off in the previous planning horizon and days off on the current horizon for agents with contract type 5x2

LDO_i	2	3	4	5	6	7	8	9	10
Days off in the previous horizon	1 and 2	2 and 3	3 and 4	4 and 5	5 and 6	6 and 7	1 and 7	5, 6, and 7	4,5,6, and 7
Days off on the current horizon	1-2, 1-3 or 1-4	2-3, 2-4 or 2-5	3-4, 3-5 or 3-6	4-5, 4-6 or 4-7	5-6 or 5-7	6-7, 1&7 or 1-2	1-2, 1&7, or 1-3	6 -7 or 1&7	6 and 7

If $LDO_i = 99$ or $LDO_i = 7$: Constraints (32A) are applied.

If $2 \leq LDO_i \leq 6$: Constraints (47C) are applied

- $$\begin{cases} w_i^{LDO_i - 1} + w_i^{LDO_i} = 0 \\ w_i^d = u_i, \forall d = 1..D / d \leq LDO_i - 2 \text{ or } d \geq LDO_i + 3, \forall i = 1..N / CT_i = 4 \\ w_i^{LDO_i + 1} \leq w_i^{LDO_i + 2} \end{cases} \qquad (47C)$$

If $LDO_i = 8$: Constraints (48C) are applied

- $$\begin{cases} w_i^4 = w_i^5 = w_i^6 = u_i \\ w_i^1 = 0 \\ w_i^2 + w_i^7 = u_i \\ w_i^2 \le w_i^3 \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (48C)$$

If $LDO_i = 9$: Constraints (49C) are applied

- $$\begin{cases} w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \\ w_i^7 = 0 \\ w_i^1 + w_i^6 = u_i \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (49C)$$

If $LDO_i = 10$: Constraints (50C) are applied

- $$\begin{cases} w_i^1 = w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \\ w_i^6 = w_i^7 = 0 \end{cases}, \forall i = 1..N / CT_i = 4 \qquad (50C)$$

Constraints (47C)-(50C) allows a break time from 2 to 4 days between any 2 consecutive sets of 5 workdays (see Table D.6).

Contract 6x1

Table D.7. Relations between the last day off in the previous planning horizon and days off on the current horizon for agents with contract type 6x1

LDO_i	1	2	3	4	5	6	7	8
Days off in the previous horizon	1	2 or 1 and 2	3 or 2 and 3	4 or 3 and 4	5 or 4 and 5	6 or 5 and 6	6 and 7	7 only
Days off on the current horizon	1 or 1 and 2	2 or 2 and 3	3 or 3 and 4	4 or 4 and 5	5 or 5 and 6	6 or 6 and 7	7	1 or 7

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$ or $LDO_i = 8$: Constraints (33A) are applied.

If $1 \le LDO_i \le 6$: constraints (51C) are applied

- $$\begin{cases} w_i^{LDO_i} = 0 \\ w_i^d = u_i,\ d = 1..D / d \le LDO_i - 1 \text{ or } d \ge LDO_i + 2 \end{cases}, \forall i = 1..N / CT_i = 5 \qquad (51C)$$

If $LDO_i = 7$: constraints (52C) are applied

- $$\begin{cases} w_i^7 = 0 \\ w_i^d = u_i, \forall d = 1..(D-1) \end{cases}, \forall i = 1..N / CT_i = 5 \qquad (52C)$$

Constraints (51C) and (52C) allows a break time from 1 to 2 days between any 2 consecutive sets of 6 workdays (see Table 17).

Contract 5x1

Table D.8. Relations between the last day off in the previous horizon and the days off on the current horizon for agents with contract 5x1

LDO_i	2	3	4	5	6	7	8
Days off on the previous horizon	2 or 1 and 2	3 or 2 and 3	4 or 3 and 4	5 or 4 and 5	6 or 5 and 6	6 and 7	7 only
Days off on the current horizon	1 and 7 or 1 and 2	2 or 2 and 3	3 or 3 and 4	4 or 4 and 5	5 or 5 and 6	6 or 6 and 7	6 or 6 and 7 or 1 and 7

Depending on the value of LDO_i, we have different constraints, as follows:

If $LDO_i = 99$: Constraints (34A) are applied.

If $3 \leq LDO_i \leq 7$: Constraints (53C) are applied.

- $$\begin{cases} w_i^{LDO_i - 1} = 0 \\ w_i^d = u_i,\ d = 1..D / d \leq LDO_i - 2 \text{ or } d \geq LDO_i + 1 \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (53C)$$

If $LDO_i=2$: Constraints (54C) are applied.

- $$\begin{cases} w_i^1 = 0 \\ w_i^2 + w_i^7 = u_i \\ w_i^3 = w_i^4 = w_i^5 = w_i^6 = u_i \end{cases}, \forall i = 1..N / CT_i = 6 \qquad (54C)$$

If $LDO_i=8$: Constraints (55C) are applied.

- $$\begin{cases} w_i^1 + w_i^6 = u_i \\ w_i^1 \geq w_i^7 \\ w_i^2 = w_i^3 = w_i^4 = w_i^5 = u_i \end{cases} ,\forall i = 1..N / CT_i = 6 \qquad (55C)$$

Constraints (53C)-(55C) allow a break time from 1 to 2 days between any two consecutive sets of five workdays.

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FOLIO ADMINISTRATIF

THESE DE L'UNIVERSITE DE LYON OPEREE AU SEIN DE L'INSA LYON

NOM : DOAN DATE de SOUTENANCE : 23/07/2020

Prénoms : Minh-Phuoc

TITRE : PROBLÈME DE CONSTITUTION ET DE PLANIFICATION D'ÉQUIPES DE TRAVAIL: MODÈLES ET EXPÉRIMENTATIONS DANS LE CONTEXTE DE SERVICES AUX ENTREPRISES

NATURE : Doctorat Numéro d'ordre : 2020LYSEI060

Ecole doctorale : InfoMaths (ED512)

Spécialité : Génie industriel

RESUME :

Les sociétés de services aux entreprises constituent des équipes de travail avec leurs agents et organisent leur planning pour satisfaire les demandes clients. De multiples contraintes doivent être respectées, et plusieurs critères de performance économique et sociale doivent être atteints. Une méthode d'aide à la décision multicritère devient ainsi indispensable, particulièrement dans un contexte de demande variable. Une caractérisation du problème générique sous forme de diagramme de classes, contenant toutes les caractéristiques des clients, demandes, agents, itinéraires, et véhicules, nous permet d'identifier des variantes du problème dans le contexte de service aux entreprises comme dans celui de service à la personne. Nous avons investigué deux variantes s'inspirant d'un problème réel d'une entreprise brésilienne de service aux entreprises, dans des contextes de demandes stable et variable. Par une revue de la littérature, nous identifions des leviers organisationnels potentiels pour accroître la flexibilité des agents, et des approches de modélisation et de résolution appropriées. Nous utilisons la programmation linéaire à variables mixtes. Dans le contexte de demande stable, nous cherchons le compromis entre coûts et temps de trajet domicile-travail des agents dans une approche à deux niveaux : une planification hebdomadaire cyclique pour les nouveaux clients assurant la stabilité d'affectation sur un long terme et, à une fréquence donnée, une re-planification pour tous les clients actifs permettant une optimisation globale. Lorsque les demandes sont variables, nous optimisons les coûts de déplacement, l'équité de la charge de travail entre agents, et leur préférence pour les périodes de travail. La planification étant créée pour un horizon court sans répétitivité, l'ajout de zones tampons entre des horizons consécutifs permet de relâcher leur dépendance ; dans cette variante, des leviers organisationnels, tels que des contrats de travail flexibles et la polyvalence des agents, sont également considérés.

MOTS-CLÉS : constitution d'équipes, planification de personnel, programmation linéaire à variables mixtes, aide à la décision multicritère, variabilité des demandes, flexibilité des ressources.

Laboratoire (s) de recherche : Décision et Information pour les Systèmes de Production (DISP)

Directeur de thèse: BOTTA-GENOULAZ Valérie

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FREIN, Yannick	Professeur, Université Grenoble Alpes	Président
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NORRE, Sylvie	Professeur, Université Clermont Auvergne	Rapporteur
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