A skill-based multi-objective optimization model for job rotation and job variety in a last-mile delivery station

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1 Introduction

Workforce scheduling—the systematic assignment of workers to workstations—is fundamental for optimizing productivity and promoting employee well-being. Traditional scheduling models mainly emphasize shift coverage and cost minimization, often overlooking factors such as ergonomic safety. This can lead to increased musculoskeletal disorders (MSDs)—one of the primary causes of work-related illness— particularly in physically demanding sectors such as logistics [2], where job rotation has been demonstrated to be a viable alternative for MSD prevention [1]. This research proposes a novel multi-objective Mixed Integer Linear Programming (MILP) model that maximizes job rotation as the primary and job variety as the secondary criterion within a single lexicographic objective function, while allowing for the inclusion of reinforcement mechanisms when needed to ensure feasible and implementable solutions. The model is validated through application to a real case of a last-mile delivery station and the obtained results are compared against existing schedules obtained by a manual process. Our findings contribute to the emerging field of human-centric scheduling and provide practitioners with an actionable decision-making tool.

2 Methodology

The case study examines a French last-mile delivery station responsible for parcel sorting and final customer dispatch operations. The facility includes 10 distinct job roles and over 30 regular employees, operating under a weekly rotation schedule that accounts for employee qualifications—training, availability, and medical restrictions—and operational requirements—job-specific staffing needs and daily rotation restrictions between jobs to prevent repetitive strain on muscle groups. The job rotation schedule pursues two hierarchical objectives:

1. Maximize *job rotation rate = (# rotated employees / # employees required to rotate) x 100%*
2. Maximize *job variety = # different jobs performed per employee per week*

A MILP model is developed to solve this problem. If no feasible solution is found with predefined staffing, temporary reinforcements are introduced into the schedule to guarantee feasibility. The problem considers a set of jobs J (excluding those that do not require rotation), a set of employees E, composed of regular workers E^r and reinforcements E^f, and a set of days D, divided into last week D^- and next week D^+. Each day, a number of employees d_{jt} is required to perform each job j $\in J$. An employee can only be assigned to a job if they are trained and have no medical restrictions, represented by the binary parameter s_{ij}. Employees contribute to job rotation only after a minimum employment duration, modeled by the binary parameter rc_i. The decision variables are:

- x_{ij}^t: 1 if employee i ∈ E is assigned to job j ∈ J on day t ∈ D; 0 otherwise
- w_{ij}: 1 if employee i ∈ E performs job j ∈ J on at least one day t ∈ D; 0 otherwise
- r_{ij}^t: 1 if employee i ∈ E^r rotates into job j ∈ J at day t ∈ $D \setminus \{0\}$, from a compatible job at t−1

We consider the optimization of three objective functions: 1. Maximization of job rotation; 2. Minimization of reinforcements, where $R = |D||E^r|$ (total possible rotations) ensures that reinforcements are used only when no feasible solution is found under predefined staffing; and 3. Maximization of job variety, where $W = \frac{1}{|E^r||J|}$ bounds the job variety term between 0 and 1, ensuring that it does not compromise job rotation. The objectives are prioritized in the order listed above, which allows them to be represented by a single objective function *(1)* using a lexicographic structure:

$$Max\ Z = \underbrace{\textstyle\sum_{i\in E^r}\sum_{j\in J}\sum_{t\in D\setminus\{0\}} r_{ij}^t}_{1} - \underbrace{R\left(\textstyle\sum_{i\in E^f}\sum_{j\in J}\sum_{t\in D} x_{ij}^t\right)}_{2} + \underbrace{W\left(\textstyle\sum_{i\in E^r}\sum_{j\in J} w_{ij}\right)}_{3} \qquad (1)$$

Equations 2-7 illustrate the model's constraints. They ensure that *(2)* daily staffing demand is satisfied; *(3)* job assignments comply with each employee's training and medical eligibility; *(4)* each employee is assigned to at most one job per day, except for reinforcements. *(5)* and *(6)* maintain logical consistency between x_{ij}^t and w_{ij}, while *(7)* preserves rotation feasibility by allowing transitions only between ergonomically compatible jobs within the set C_j. This MILP model is implemented using the PuLP library in Python with HiGHS as the solver, both are open source.

$$\textstyle\sum_{i\in E} x_{ij}^t \geq d_i^t \quad \forall\, j \in J, t \in D^+ \qquad (2)$$

$$x_{ij}^t \leq s_{ij} \quad \forall\, i \in E^-, j \in J^-, t \in D^+ \qquad (3)$$

$$\textstyle\sum_{j\in J} x_{ij}^t \leq 1 \quad \forall\, i \in E^-, t \in D \qquad (4)$$

$$\textstyle\sum_{t\in D} x_{ij}^t \leq |D|\, w_{ij} \quad \forall\, i \in E, j \in J^- \qquad (5)$$

$$w_{ij} \leq \textstyle\sum_{t\in D} x_{ij}^t \quad \forall\, i \in E, j \in J^- \qquad (6)$$

$$2r_{ij}^t \leq rc_i\left(x_{ij}^t + \textstyle\sum_{k\in C_j} x_{ik}^{t-1}\right) \quad \forall\, i \in E, j \in J^-, t \in D \setminus \{0\} \qquad (7)$$

3 Results and Conclusions

To assess the effectiveness of the proposed MILP model, a comparative experimentation was conducted on real-world data from January to August 2025, benchmarking optimized schedules against actual operational planning. The model achieved an average job rotation rate of 98%, with improvements of up to 7% in certain weeks. Regarding job variety, the model reached an average of 3.8 jobs per employee-week, with gains of up to 10% observed in specific weeks. In some weeks, job variety was higher under manual planning; however, this often came at the expense of suboptimal rotation rates. Overall, the MILP model achieved a more consistent and superior balance between job rotation and job variety while fully meeting operational constraints. In addition, the model reduced scheduling time by 83% compared to manual planning, strengthening both efficiency and ergonomics. Its lexicographic formulation and reinforcement mechanism ensure feasibility while prioritizing human-centric objectives. Future research could address demand and operational uncertainty and explore applications across diverse industrial contexts.

References

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