Department of Industrial Systems Engineering and Management
IE3100M Systems Design Project | Group 18 (AY2021/2022)

Resource Planning and Workload Forecasting Model for Warehousing Operations

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PROJECT FLOW

Problem Definition & Project Discussion → Proposed Approach: Python & Excel Interface → Data Cleaning → Development of Python script & Interface → Review and Refine (AGILE Methodology) → Documentation, Model Validation & User Testing

PROBLEM BACKGROUND

3 Phases of Inbounding Process at Cummins

- Inbound | Packaging | Putaway

In each phase, a series of activities are performed before being passed on to the subsequent phase.

Different product types may undergo a different process based on their respective requirements.

CURRENT SITUATION

Manpower allocation to the processes done manually

Unoptimized manpower allocation

= cost & efficiency consequences

Often caused by low productivity & labour shortage.

PROBLEM DESCRIPTION

Arrival of Inbound Shipments & Outbound Orders → Processes run simultaneously for various product types

Capacity constraint due to limited resources + dynamic nature of processes → **bottlenecks** may arise

PROBLEM OBJECTIVE

To deliver a optimization resource planning and workload forecasting model to help improve making resource staffing level decisions of the operations team.

MODEL CRITERIA

Model built should account for:

1. Dynamic inbound workload considering variability in lead times
2. Dynamic outbound workload with fixed date-lines to achieve on-time delivery targets

MODEL GOAL

- → **To aid operation managers in optimizing resource allocation of inbounding process, to achieve a target level of productivity**
- → **To optimize manpower allocation within a warehouse in 2 hour intervals, and provide 12 weeks forecast of allocation to achieve its target level**

ASSUMPTIONS

- Total manpower available, capacity of workstations and process route of each product type are fixed.
- Maximum queue length at all workstations is infinite.
- Shift configuration and working days are not considered.
- Workers are assumed to be homogenous, both in terms of skills and experience level.
- Time taken for workstation to clear jobs before arrival of new jobs is greater than 2 hours.
- Output for each iteration is fairly accurate & is used as input for subsequent iterations.

MODEL INPUT

- → Weeks to forecast (default:12 weeks)
- → Maximum manpower available for each shift
- → Workstation capacity for different processes (ID, PKG and PA)
- → Weightage to Manpower & Productivity
- → Arrivals & Backlog of each workstation (derived from Cummins historical data)

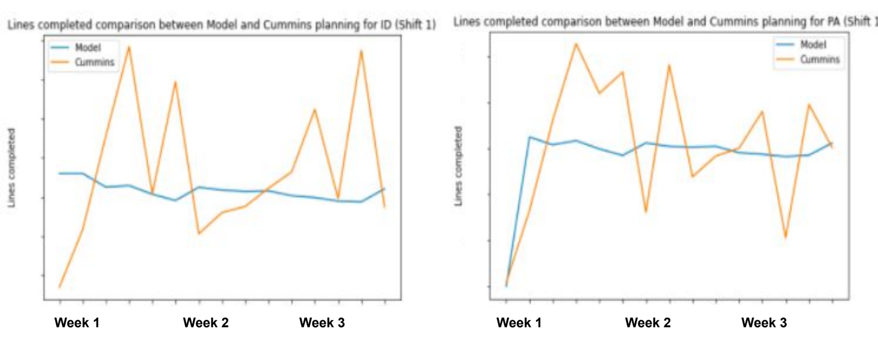
MODEL OUTPUT

- → Excel CSV file detailing daily allocation for stated weeks to each workstation
- → Excel CSV file detailing weekly allocation of manpower required for the stated weeks

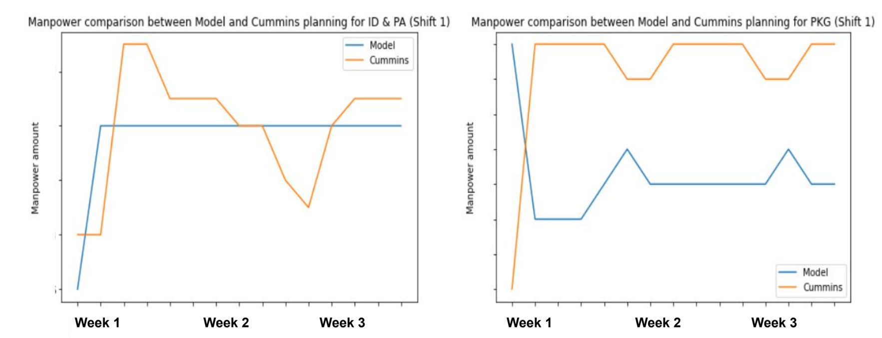
VALIDATION

Cummins' Allocation vs Model Recommendation (Timeframe: 3 Weeks)

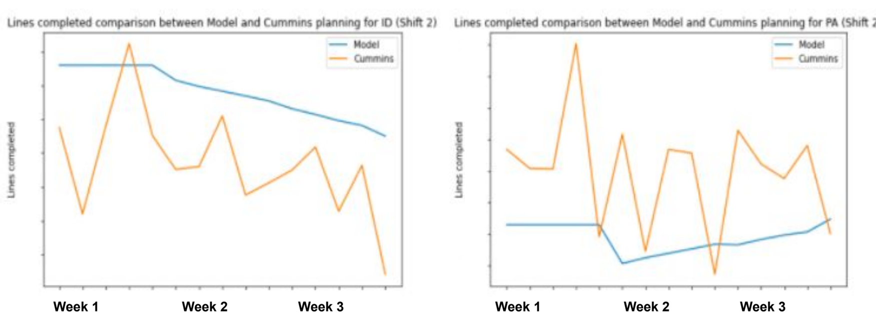
Lines Completed (Shift 1) – Left: ID | Right: PA



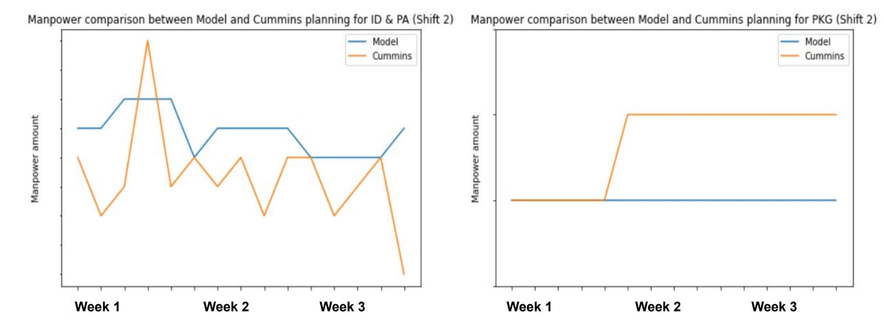
Manpower Allocated (Shift 1) – Left: ID & PA | Right: PKG



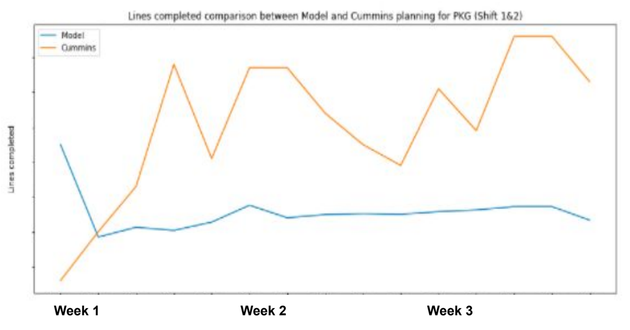
Lines Completed (Shift 2) – Left: ID | Right: PA



Manpower Allocated (Shift 2) – Left: ID & PA | Right: PKG



Lines Completed – PKG



- → Model allows for a more balanced lines completion compared to that of Cummin's allocation in general.
- → Model generally allocated more consistent but lesser workers except for ID & PA in shift 2

LIMITATION

- → Our model adopts linear programming with real values to prioritise model processing speed over accuracy. Real values are rounded.
- → Our solver is incompatible with the VBA interface software on Cummins' side. Thus, we are unable to implement a user-friendly interface for them.
- → Less advanced solvers used, since a more advanced solvers such as Gurobi requires a paid license.

MODEL FORMULATION

DATA CLEANING

- Our model seeks to provide an efficient manpower allocation over 5 working days per week, disregarding overtime hours - non-working days scheduled arrivals to the next nearest working day
- Multilayer Perceptron (MLP) was used to predict missing values of data input files

OBJECTIVE FUNCTIONS

MAXIMIZE operational productivity level & MINIMIZE required workers allocated

$$Min_x z = w_1 \frac{\sum_{i\in I} \frac{M_i - M_{max_i}}{M_{max_i}}}{I} + w_2 \frac{\sum_{i=4n-3}^{N=\frac{I}{4}} \sum_{j\in J} \left(\frac{\alpha_{target} - \alpha_{ij}}{\alpha_{target}} \right) \frac{B_{ij}}{\sum_{k\,\forall j} B_{ik}}}{N}$$

Objective function set minimises sum of deviations of the goals wrt. their respective weights

CONSTRAINTS

Total manpower allocated per interval ≤ Maximum manpower available: $M_i \leq Mmax_i, \forall i \in I$

Sum of manpower allocated to each workstation in an interval ≤Total manpower allocated per interval:

$$\sum_{j\in J} x_{ij} = M_i, \forall i \in I, \forall j \in J$$

Equal amount of total available manpower for every interval in a shift:

$$M_i = M_{i+1} = M_{i+2} = M_{i+3}, \; for\; i = 4n - 3, \forall n \in N = \{1 \leq n \leq 120\}$$

Equal amount of total available manpower for every shift in a week:

$$M_i = M_{i+8} = M_{i+16} = M_{i+24} = M_{i+32}, \; for\; i = 40n - 39, \forall n \in N = \{1 \leq n \leq 12\}$$

$$M_i = M_{i+8} = M_{i+16} = M_{i+24} = M_{i+32}, \; for\; i = 40n - 35, \forall n \in N = \{1 \leq n \leq 12\}$$

Allocated manpower ≤ workstation capacity constraint: $x_{ij} \leq L_{ij}, \forall i \in I, \forall j \in J$

Alpha as the ratio of completed units over the combined arrival and backlog:

$$\sum_{i}^{i+3} x_{ij}\mu_j \geq \alpha_{ij}([\sum_{i}^{i+3} A_{ij}] + B_{0j}), for\; i = 1, \forall j \in J$$

$$\sum_{i=n}^{n+3} x_{ij}\mu_j \geq \alpha_{ij}([\sum_{i}^{i+3} A_{ij}] + B_{i-1j}), for\; i = 4n - 3, \forall n \in N = \{2 \leq n \leq 120\}, \forall j \in J$$

Flow control constraint:

$$x_{ij}\mu_{ij} \leq A_{ij} + B_{0j}, \; i = 1, \forall j \in J$$

$$x_{ij}\mu_{ij} \leq A_{ij} + B_{i-1j}, \; i \neq 1 \,\&\&\, \in I, \forall j \in J$$

Backlog carry forward constraint:

$$B_{ij} = A_{ij} + B_{0j} = x_{ij}\mu_j, \; i = 1, \forall j \in J$$

$$B_{ij} = A_{ij} + B_{i-1j} = x_{ij}\mu_j, \; i \neq 1 \; and \; \in I, \forall j \in J$$

Goal Programming adopted to balance the two objectives

RECOMMENDATION

- → Utilise stronger and more robust solvers to resolve the limitations of our current model. (e.g. Gurobi, CPLEX)
- → Implement a user-friendly interface.
- → Incorporate temporary workforce and instances of overtime to reflect real life operations.
- → Enlarge the scope to include outbound and different packaging processes (Auto-bag, Hand pack, Heavy pack 1, Heavy pack 2)

CONCLUSION

- → Successfully balances between minimising manpower and maximising items' completion rate to return a feasible output.
- → Successfully forecasts the potential manpower allocation that is required of Cummins based on past data.
- → Allocates efficient manpower to reach similar completion rate despite its limitations.
- → Further refinements and overcoming its limitations will certainly bolster the performance of the model.

KEY TECHNICAL SKILLS ACQUIRED

Systems Thinking & Problem Solving	Machine Learning
Project Management	Python Programming Language