Optimization model for maintenance packaging allocations

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Overview

Strategic Factors and Inaccurate Method

The maintenance strategy, established during the product development phase, is considered one of the strategic factors for a complex system's high productivity.

Scenario

- Stakeholders Needs
  - An organized and flexible maintenance plan.
  - Tasks distributed in a way (packages) that minimize the maintenance costs, maximize fleet availability.
  - Conforming to safety constraints
  - Proactive identification of improvements
  - A decision support system to optimize the maintenance planning

Scenario

Inefficient preventive maintenace consequences

- Increase in downtime and decline in profit margin
- Possible Disruption of the flight network
- Losses on Investment Return
- Decrease in Future sales and in the reputation of the aircraft market

Problem Definition

Inaccurate Method for maintenance plan development and absence of continuous data analysis resulting in a conservative maintenance plan

Researchers recognize the critical role played by inaccuracy in the methodologies used to define the preventive maintenance intervals.

- [Liu *et al.* 2006]
- [Ahmadi *et al.* 2010]
- [America, A. (2015)] $\rightarrow$ "good engineering judgment"

Conservative Maintenance Plan

Aircraft Task Interval Escalation

Efforts that benefit airlines by lowering costs and downtime after several years of operation show the opportunity of improvements .

Boeing's B737 aircraft interval escalation (2004-2005):

Table: Estimated maintenance savings over 20 years

Parameters	**Savings**
Labor- hour per airplane	2,586
Cost Savings per airplane	$ 155,193
Downtime gained	40 days
Revenue per airplane	$1,097,120

$\rightarrow$ USD 25,046,400

Problem Specification

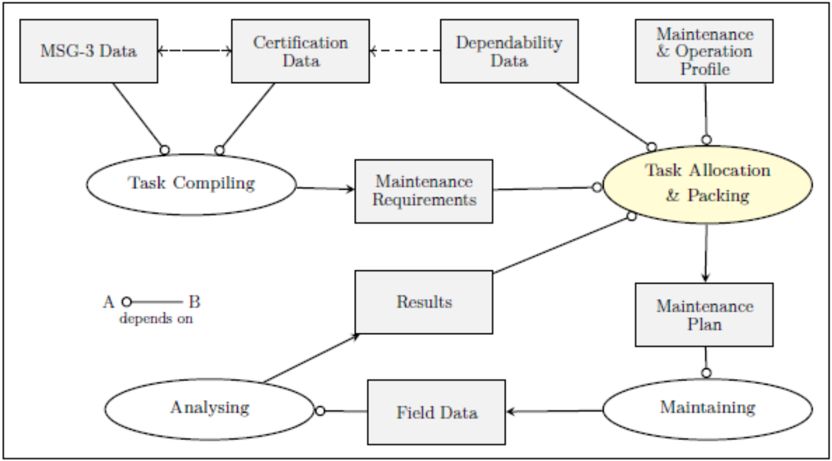
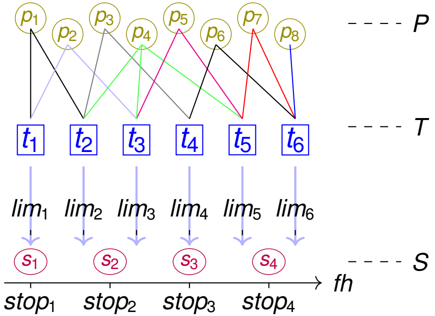


Figure: Task Allocation Problem

Problem Details - Maintenance Packages

- $T = \{1, 2, 3 \ldots, |T|\} \rightarrow$ Maintenance Tasks indexed by j.
- $P = \{1, 2, 3 \ldots, |P|\} \rightarrow$ Preparation Tasks indexed by k
- $S = \{1, 2, 3 \ldots, |S|\} \rightarrow$ Packages indexed by i

1. Task T_j is assigned to package S_i if $stop_i \leq lim_j$
2. p_k can be necessary to one or more tasks T_j S_i will be composed of one or more task T_j



Problem Details -Packaging and Out of Phase Tasks

- Group tasks → increase availability
- But some tasks are expected to be planned as *Out Of Phase* (OOP)

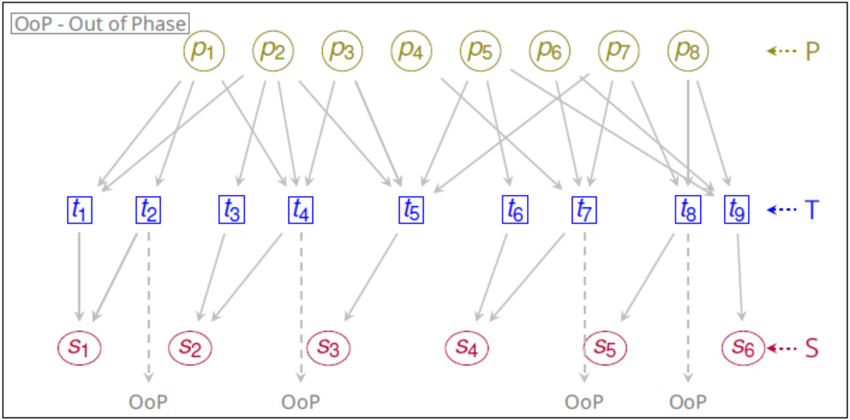


Figure: Task Allocation Problem

Proposal

Create and test a model to generate optimum and resilient maintenance plans that consider the effects of packaging, the likelihood of failures, and continuous updating capability to meet the needs of stakeholders.

Hypothesis

H1 Gains in efficiency (same safety level)

H2 Responsiveness

H3 Learning capability

Conceptual Model

- optimization module receives information from maintenance requirements
- MIP Solver finds the optimal allocation of tasks
- The Updating mechanism adapts the planner based on the current data

Figure: Conceptual Model

Literature Review

Table: Literature, solution methods and features

	Objectives		Methods		Features			
Approach by	Min Cost	Max Avail	IP	Heu	Life phase	Op Cost	Prob CM	Packing gain
[Muchiri *et al.* (2009)]	■	.	.	⊡	O	.	.	⊡
[Holzel *et al.* (2012)]	■	.	■	⊡	O	⊡	.	.
[Li *et al.* (2015)]	■	.	.	■	O	.	.	⊡
[Senturk *et al.* (2018)]	⊡	■	.	⊡	O	.	.	.
[Witteman *et al.* (2021)]	■	■	.	■	O	.	.	⊡
[Lee *et al.* (2022)]	■	.	■	⊡	O	.	■	⊡
This work	■	■	■	■	$D + O$	■	■	■

■ completely ⊡ partially O operational D development

IP integer programming **Heu** heuristics

Contributions

This study adds to existing researches the integration of important parameters to find a optimal solution for the task allocation problem:

- MSG-3 and maintainability task analysis data (labor, access data, preparation and follow-on activities)
- Probability of failures and associated costs.
- savings as a result of task packaging
- opportunity cost due to aircraft unavailability
- Study of using the field or design data to make maintenance plan resilient.

Objective Function

Minimize :

$$\left\{ \left[\sum_{i=1}^{n} \sum_{j=1}^{t} x_{ij} * (pmtc_j + \sum_{q=1}^{n(B_i)} prepc_q) * Q_i \right] + \left[\sum_{j=1}^{m} E_j * cmtc_j * Q_i \right] \right\} \quad (1)$$

$$Q_i = \frac{T_{max}}{stop_i} \quad (2)$$

$$E_j = \sum_{j=1}^{t} x_{ij} * \frac{1}{T} \int_0^T \lambda_j(t) dt * stop_i \quad (3)$$

Constraints

task maximum limit must be equal or greater than the package interval

$$X_{ij} * lim_j >= X_{ij} * stop_i, for\ j \in \{1, 2, 3, \ldots, m\},\ for\ i \in \{1, 2, 3, \ldots, n\} \quad (4)$$

Preparation tasks are not duplicated in the package

$$\sum_{i=1}^{n} P_k = 1,\ for\ k \in \{1, 2, 3, \ldots, p\} \quad (5)$$

Algorithms

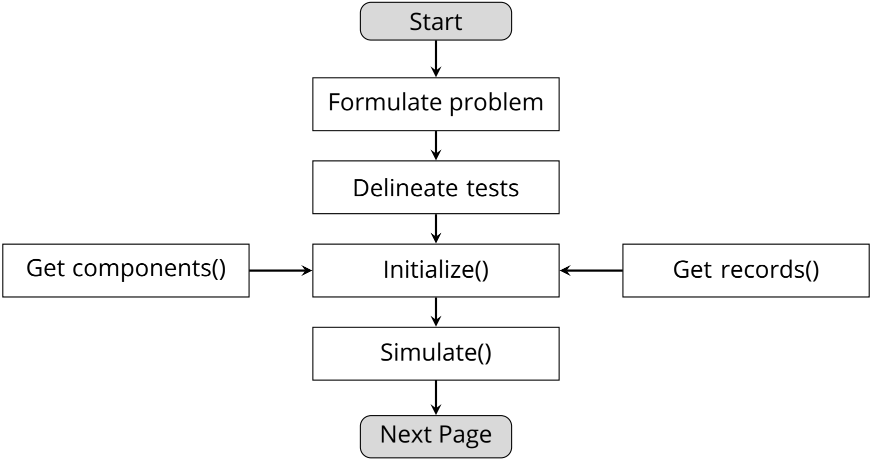


Figure: Tests Process I

Algorithms

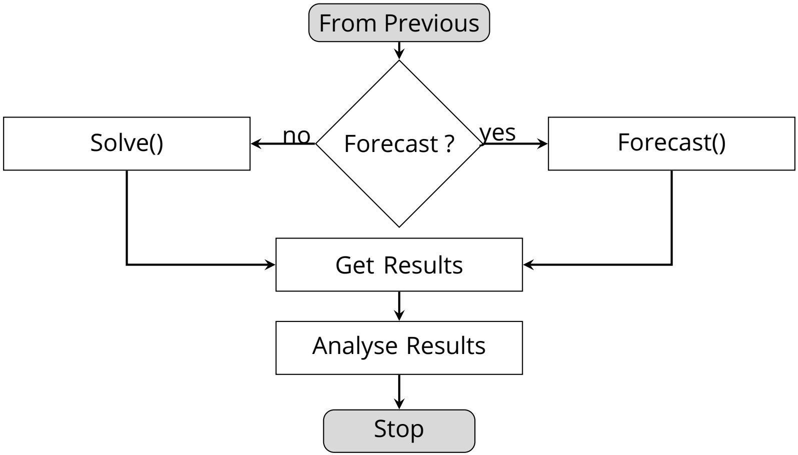


Figure: Tests Process II

Tools

- First validation tests $\rightarrow$ Microsoft Excel solvers.
- Remaining tests $\rightarrow$ Python 3 MIP solver.

The MIP solver used in this work was the Branch and Cut developed and maintained by [Forrest *et al.* 2020] as well as Python 3, with the following libraries:

- numpy: [Harris *et al.* 2020]
- pandas: [McKinney *et al.* 2010]

Constants

- $OCD = 70,000.00$, daily OC (USD), [Senturk *et al.* (2018)]
- $OHD = 8$, operating hours per day
- $HOC = \lfloor \frac{OCD}{OHD} \rfloor$, hourly OC
- $MHC = 70.00$, man-hour cost (USD)
- $CMF = 3.0$, corrective maintenance factor.

A supervised learning method will be used to predict and update the constants and input data to supply the Mixed Integer Programming (MIP) solver with maintenance parameters.

Premisses

- Items considered as good as new after(AGAN) maintenance.
- Failures are evident FEC 6 and FEC 7 as per MSG-3 analysis.
- items are replaced in event of failure and during the inspection
- All tasks should be included in one of the pre-defined packages
- Resources limitations are not considered
- Downtime calculation considers one specialist per task

Components Data

Table: Components List

Item	*Description*	λ_j	lim_j	mat_j	mh_j	A_j
$comp_1$	Starter generator	1.56E-04	1000	518.316	2.63	[2 3 5 12]
$comp_2$	Fuel Pump	7.74E-04	1500	387.319	3.28	[2 3 5 7 9 10]
$comp_3$	Main Battery	8.55E-04	300	564.245	2.71	[2 5 11 13]
$comp_4$	Ejection Pump	7.74E-04	3000	185.569	3.80	[2 3 5 7 8 14 15 16
$comp_5$	Hydraulic pump	3.33E-05	4500	158.253	4.60	[2 3 5 13]
$comp_6$	Engine	1.00E-05	4800	152.667	11.06	[2 3 6 12 13]
$comp_7$	Hydraulic Check Valve	1.37E-05	1000	329.771	0.97	[4 10 1]
$comp_j$	...	...	...	...	...	[...]
$comp_{86}$	Spoiler Actuator	3.42E-05	400	154.656	1.17	[15 9 13]

Model Validation I

Table: Comparison

	T_1	$item_1$	$item_2$	$item_3$	$item_4$	$item_5$	$item_6$	Cp_i	α_i
T1	300	0	0	1	0	0	0	12046.00	1.0
T2	900	1	0	0	0	0	0	11690.35	1.0
T3	1500	0	1	0	0	0	0	14579.60	1.0
T4	3000	0	0	0	1	0	0	16891,00	1.0
T5	4500	0	0	0	0	1	0	20447.00	1.0
T6	4800	0	0	0	0	0	1	49161.70	1.0

	T_1	$item_1$	$item_2$	$item_3$	$item_4$	$item_5$	$item_6$	Cp_i	α_i
T1	300	0	0	1	0	0	0	12046.00	1.0
T2	900	1	0	0	0	0	0	11690.40	1.0
T3	1500	0	1	0	1	0	0	23336.30	0.742
T4	3000	0	0	0	0	0	0	-	-
T5	4500	0	0	0	0	1	1	69897.30	0.961
T6	4800	0	0	0	0	0	0	-	-

Model Validation II

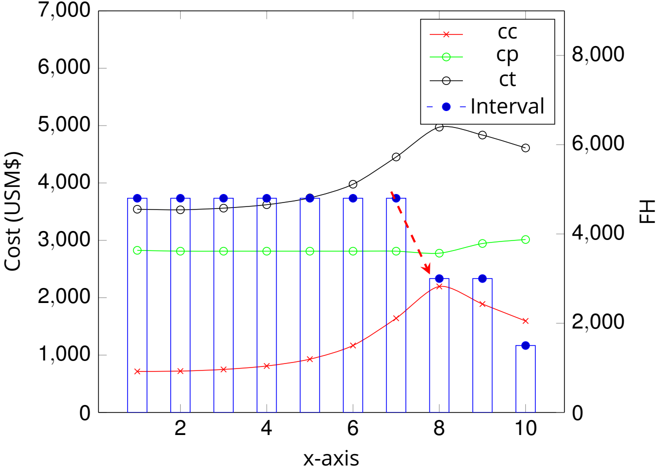


Figure: Sensitivity Test - 1

Packaging Effect

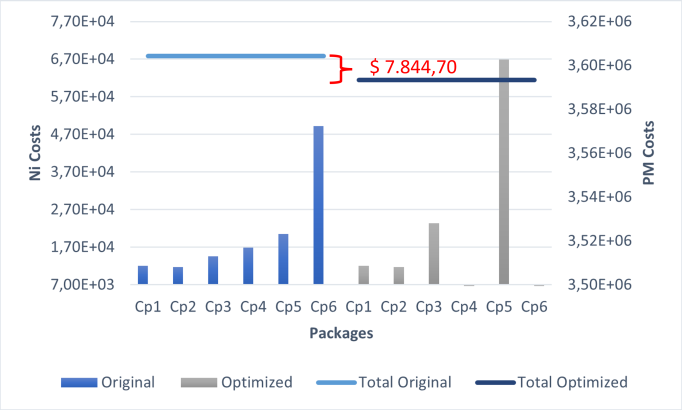


Figure: Packaging Economy Validation.

Packaging Costs

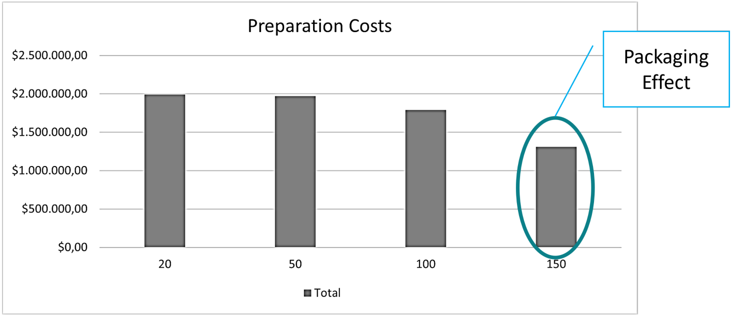


Figure: Preparation costs for different steps

Corrective Costs

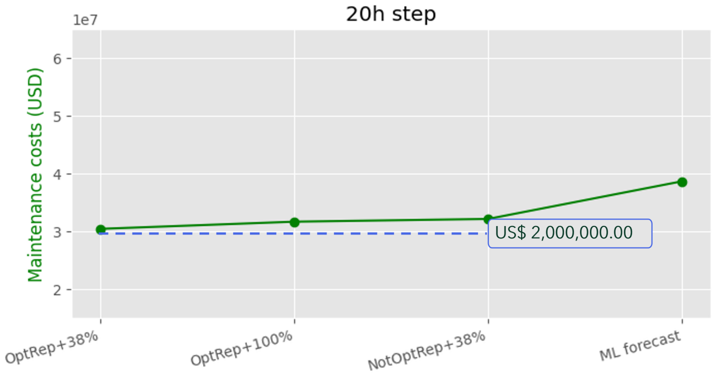


Figure: Influence of Corrective Cost - 20h steps

Optimization Effects I

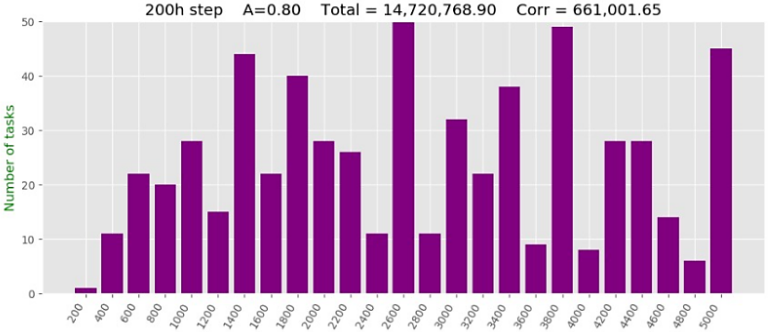


Figure: 200-hour Steps Tasks Distribution Without Optimization

Optimization Effects II

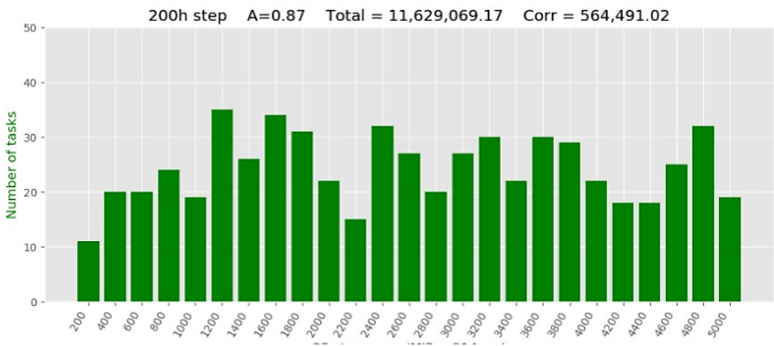


Figure: 200-hour Steps Tasks Distribution With Optimization

Status	A_0	Total Cost	Corrective Cost
Not Optimized	80%	$ 14,720,768.90	$ 661,001.65
Optimized	87%	$ 11,629,069.17	$ 564,491.02
Gain	7%	$ 3.091.699,20	$ 96.510,63

Conclusions

- Grouping activities using the optimization model saves total maintenance expenses.
- Proposed model performs betterthan other traditional maintenance planner methods regarding costs and availability.
- An interactive framework able to provide integration between different actors, can allow complex systems to remain resilient throughout their respective life cycles.

Next Steps

1. ML for estimations based on maintenance records
2. Use of system monitoring capabilities to update the maintenance plan
3. Process to include OOP task in the IVHM
4. Evaluation of the model using three different operators` flight and maintenance profiles.
5. Inclusion the consideration to use the overnight period in the optimization.

Acknowledgments

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The End

Questions? Comments?

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