



Airline Route Planning using PERT/CPM — OR Literature Study

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1. Introduction

This study reviews 20 published research papers that apply PERT and CPM network scheduling to aviation, and uses them to model the launch of a new airline route as a project. The aim is to show how a route launch — from market study to the first scheduled flight — can be planned, timed and controlled with project-network techniques.

1.1 Operations Research

Operations Research (OR) is the use of mathematical models to support decisions about limited resources. A real problem is translated into an objective (what to minimise or maximise), decision variables and constraints, and then solved with a suitable algorithm. Common OR families include linear programming, transportation and assignment models, network models, queuing and simulation.

1.2 Network models: PERT and CPM

PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are network models for project scheduling. Both break a project into activities, link them by precedence, and draw them as a network. The longest path through that network is the critical path, and its length is the minimum project duration.

Feature	CPM	PERT
Origin	DuPont and Remington Rand, 1957	US Navy Polaris programme, 1958
Activity time	One fixed (deterministic) estimate	Three estimates: optimistic, most likely, pessimistic
Main output	Critical path, float, time–cost trade-off (crashing)	Expected duration, variance, probability of finishing by a date
Best suited to	Repetitive work with known times (construction, maintenance)	New, uncertain work (R&D, first-time launches)

1.3 Problem type and scope

Airline route planning is usually framed in two ways: choosing *which* route to fly (a network-design or selection problem), or planning *how* to launch a chosen route (a project-scheduling problem). This study takes the second view. Launching a route involves regulatory approval, airport slots, aircraft and crew readiness, ground handling contracts, distribution and marketing — dozens of interdependent activities with uncertain durations. That makes it a classic PERT/CPM problem: a deterministic or stochastic **project scheduling problem** whose objective is to minimise completion time (and, with crashing, cost).

The guideline asked for 1–2 papers; this study widens the base to 20 papers so that the model draws on evidence from several parts of aviation — airline operations, aircraft maintenance, airport construction and aerospace programmes — rather than a single case.

2. Research Methodology

Twenty studies published between 1965 and 2026 were selected, each applying PERT, CPM or a direct extension of them (fuzzy CPM, critical chain, Monte Carlo PERT, CPM-based LP) to an aviation problem. Because almost no published paper models a route launch end-to-end, the search covered the four operational building blocks that a new route depends on.

Search sources: Taylor & Francis, Emerald, Springer, Atlantis Press, IEEE/INFORMS (Winter Simulation Conference), ASCE Library, IIETA, and open-access university journals. Search terms combined *PERT*, *CPM*, *critical path* and *critical chain* with *aircraft turnaround*, *ground handling*, *aircraft maintenance*, *overhaul*, *airport construction* and *airline*.

Inclusion rules:

1. The paper builds an activity network (or a model derived from one) for a real or realistic aviation case.
2. It reports a critical path, project duration, completion probability or time–cost result.
3. Bibliographic details could be verified on the publisher or university repository page.

Classification used for analysis:

Theme	Link to launching a route	Papers
A. Aircraft turnaround and ground operations	Sets minimum ground time, which fixes the flight schedule and aircraft rotation	8
B. Aircraft maintenance and overhaul (MRO)	Decides when the aircraft assigned to the route is available	8
C. Airport and station infrastructure	Station readiness at the new destination	3
D. Aircraft production and assembly	Fleet delivery for network growth	1

For every paper the following data was extracted into the Excel workbook: problem, domain, objective, constraints, problem type, technique, software, data source, number of activities, headline result (before and after) and stated limitations. Where a paper reports numeric before/after values, the percentage improvement was recalculated in the workbook rather than copied.

3. The Real-Life Problem

An airline that decides to open a new route must finish dozens of linked tasks before the first paying passenger boards, and a late launch means lost revenue, wasted marketing spend and idle aircraft or crew. The problem sits in the **aviation / airline operations** domain.

3.1 What has to happen before a route opens

- **Commercial:** demand study, route economics, board approval, fare filing, reservation-system loading, sales and marketing.
- **Regulatory:** traffic rights under bilateral agreements, schedule approval from the civil aviation authority (DGCA in India), airport slots at both ends.
- **Operational:** aircraft allocation, crew route training, ground handling and fuel contracts, station set-up, proving checks and a dry run.

Many of these can run in parallel, but some cannot start until others finish — fares cannot be loaded until the schedule is fixed, and the schedule cannot be fixed until slots and aircraft are known.

3.2 Why PERT/CPM suits this problem

1. **It is a one-time project with a fixed end goal** (the inaugural flight), not a repeated flow — exactly the setting PERT/CPM was built for.
2. **Precedence is clear and mostly technological** (approval before sales, slots before schedule), so the network can be drawn without ambiguity.
3. **Durations are uncertain.** Regulatory approvals in particular can take anywhere from weeks to months, which PERT's three-time estimate captures directly.
4. **Management needs a few concrete answers:** the earliest launch date, which tasks cannot slip, how likely a target date is, and what it costs to launch sooner. These are precisely PERT/CPM's outputs.
5. **The literature shows it works in the parts of aviation a launch depends on** — turnaround (ground time sets the schedule), maintenance (aircraft availability) and airport works (station readiness), as Section 4 shows.

4. Summarised Analysis of the 20 Papers

Across the 20 papers, CPM is used in 16, PERT in 9, simulation in 5, LP/MIP in 4 and fuzzy CPM or critical chain in 2; turnaround and maintenance studies make up 80% of the sample. Full extracted data is in the *Paper_Database* sheet of the workbook.

#	Study	Theme	Technique	Headline result
1	Summers (1965)	Maintenance	CPM	First use of CPM to cut jet maintenance-check time
2	Samaranayake et al. (2002)	Maintenance	CPM + MRP	One structure for tasks and parts at Qantas
3	Wu & Caves (2003)	Turnaround	Stochastic network	Punctuality driven by scheduled ground time and



#	Study	Theme	Technique	Headline result
				service efficiency
4	Ersahin et al. (2003)	Airport works	PERT vs Monte Carlo	Simulation gives more realistic risk for Toronto Pearson terminal
5	Wu & Caves (2004)	Turnaround	Stochastic model + optimisation	Optimal buffer balances delay cost and aircraft use
6	Kuster et al. (2009)	Turnaround	Extended RCPSP	Alternative activities speed up disruption recovery
7	Atli & Kahraman (2012)	Maintenance	Fuzzy CPM	Handles vague time estimates in engine overhaul
8	Oreschko et al. (2012)	Turnaround	Critical path, Weibull times	Better off-block-time prediction
9	Makhloof et al. (2014)	Turnaround	PERT/CPM in real-time system	Live monitoring cuts ground delay
10	Al-Bazi et al. (2016)	Turnaround	Integer LP critical path	Fastest LCC turn: stairs off, air bridge on
11	San Antonio et al. (2017)	Turnaround	Monte Carlo PERT	Deplane–clean–board path critical in 99.9% of runs
12	Kulkarni et al. (2017)	Maintenance	CPM vs critical chain	A320 heavy check 5 days (8.9%) shorter
13	Dimas (2018)	Aircraft production	CPM + PERT	Only 31% chance of meeting 92-hour C-295 assembly plan
14	Nursanti et al. (2019)	Maintenance	CPM/PERT + simulation	Hawk overhaul 283 → 31 working days
15	Čileček & Teichmann (2022)	Turnaround	CPM + MILP	One staff group removed using

#	Study	Theme	Technique	Headline result
				float
16	Nahendra et al. (2022)	Airport works	PERT + CPM + crashing	34 → 32 weeks at 97.9% probability
17	Johi & Khalaf (2023)	Airport works	CPM (Primavera)	Heliport: 85 activities, 478 days
18	Daffa et al. (2025)	Maintenance	CPM	B737-900ER C-check 21.73 → 20.47 days
19	Avief et al. (2026)	Maintenance	CPM + PERT + Monte Carlo	Schedule error 17.6 → 7.4 days
20	Nurdin et al. (2026)	Maintenance	CPM + PERT + LP	A02-check 6,199 → 4,090 minutes

4.1 Theme A — Turnaround and ground operations (8 papers)

The turnaround is a small project repeated every flight, and its critical path decides how short the scheduled ground time on a new route can be. Wu & Caves showed that punctuality depends on how much buffer is built into that ground time. San Antonio et al. simulated a Boeing 737-800 turn and found the passenger path (deplane, clean, board) is critical in almost every run, averaging 34 minutes at full load. Later work moved from analysis to control: Makhloof et al. put PERT/CPM into a live monitoring system, Al-Bazi et al. and Čileček & Teichmann combined critical-path logic with integer programming to set schedules and staffing.

4.2 Theme B — Maintenance and overhaul (8 papers)

Maintenance checks are classic CPM projects: hundreds of task cards, clear precedence and costly downtime. Every study reports a shorter check once the critical path is managed — from about 6% (Daffa et al.) to 89% (Nursanti et al.). The field has moved from pure CPM (Summers, Daffa) to methods that handle uncertainty and resources: fuzzy CPM (Atli & Kahraman), critical chain (Kulkarni et al.), LP crashing (Nurdin et al.) and Monte Carlo risk models (Avief et al.).

4.3 Theme C and D — Airport works and aircraft production (4 papers)

The airport studies are closest to station set-up for a new route. Nahendra et al. used PERT probability and crashing on Gebe Airport; Johi & Khalaf scheduled an 85-activity heliport in Primavera; Ersahin et al. showed that plain PERT understated risk on Toronto Pearson's terminal. Dimas's C-295 assembly study shows PERT's practical value: a plan that looked achievable had only a 31% chance of being met.

5. Modelling and Problem Formulation

The route launch is modelled as a **project scheduling problem on an activity-on-node network**: minimise the time to the inaugural flight subject to precedence, then (with crashing) minimise the extra cost of meeting an earlier date. This is the same structure used in the reviewed papers.

5.1 Elements of the model

Element	Meaning in a route launch
Activities $i = 1 \dots n$	Tasks such as slot application, crew training, fare filing
Precedence set P	Pairs (i, j) where j cannot start before i finishes
Parameters a_i, m_i, b_i	Optimistic, most likely, pessimistic duration (weeks)
Parameters C_i^N, C_i^c, d_i^c	Normal cost, crash cost, crash (minimum) duration
Decision variable S_i	Start week of activity i
Decision variable x_i	Weeks by which activity i is shortened (crashing)
Output T	Launch week (project completion)

5.2 PERT time estimates

Each activity's duration is treated as a beta-distributed random variable:

$$t_{e,i} = (a_i + 4m_i + b_i) / 6 \quad \sigma_i^2 = [(b_i - a_i) / 6]^2$$

5.3 CPM as a linear programme (time minimisation)

Minimise T subject to $S_j \geq S_i + t_{e,i}$ for every (i, j) in P; $T \geq S_i + t_{e,i}$ for every i; $S_i \geq 0$

Solving it by hand is the forward pass ($ES_j = \max$ over predecessors of EF_i) and backward pass ($LF_i = \min$ over successors of LS_j). Total slack is $LS - ES$; activities with zero slack form the critical path.

5.4 Probability of meeting a target date D

By the Central Limit Theorem, the launch time is treated as normal with mean T and variance equal to the sum of the critical activities' variances:

$$Z = (D - T) / \sqrt{(\sum \sigma_i^2 \text{ over critical activities})} \quad P(\text{launch} \leq D) = \Phi(Z)$$

5.5 Crashing (time–cost trade-off) as an LP

The cost slope of activity i is $k_i = (C_i^c - C_i^N) / (t_{e,i} - d_i^c)$. For a target launch week D:

Minimise $\sum k_i x_i$ subject to $S_j \geq S_i + t_{e,i} - x_i$ for every (i, j) in P; $S_n + t_{e,n} - x_n \leq D$; $0 \leq x_i \leq t_{e,i} - d_i^c$; $S_i \geq 0$

This is the same structure Nurdin et al. (2026) and Nahendra et al. (2022) used for maintenance and airport projects.

5.6 Assumptions

- Activities are independent; one delay does not change another's distribution.
- Each duration follows a beta distribution defined by a, m, b.
- Only one critical path drives variance (the classic PERT simplification — tested later by simulation).
- Cost rises linearly as an activity is crashed.
- Resources (staff, budget) are unlimited unless stated; this is relaxed in the RCPSP-type papers (Kuster et al., Cíleček & Teichmann).

6. Precedence links are finish-to-start (Johi & Khalaf show start-to-start links can also be used).

6. Worked Application: Launching a New Route

The model gives an expected launch time of **29.8 weeks** along the critical path A–B–D–F–L–M–N, but simulation shows the realistic expectation is closer to 31 weeks, and launching 2 weeks earlier would cost about ₹4.4 lakh extra. The case is hypothetical: an Indian carrier opening an international route from a Tier-2 city to a Gulf hub. Time and cost figures are illustrative assumptions informed by the activity types in the reviewed papers; all calculations are in the *Route_PERT_CPM, Probability, Crashing* and *Monte_Carlo* sheets.

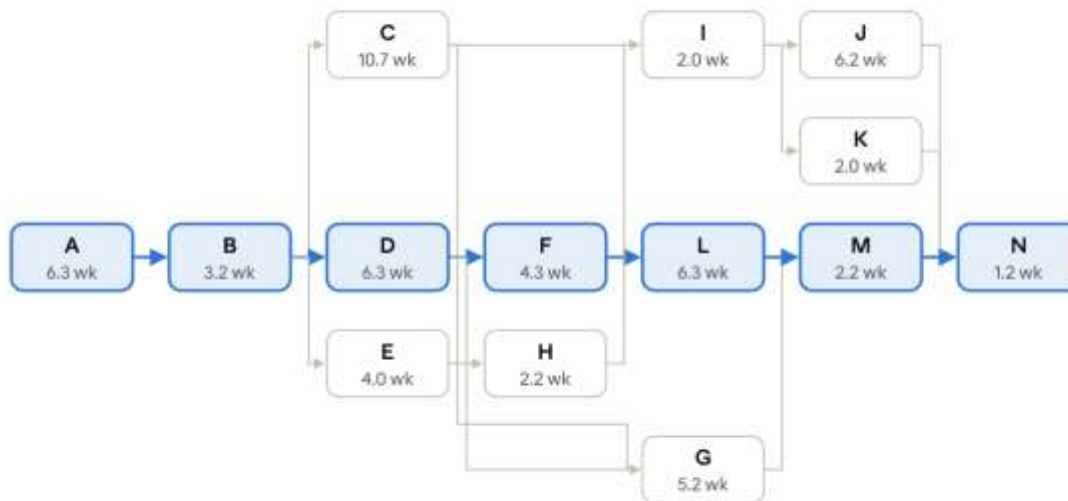
6.1 Activities and results of the forward and backward pass

Cod e	Activity	Depends on	a	m	b	t_e (wk)	Slack (wk)
A	Market and demand study	—	4	6	10	6.33	0
B	Route economics and board approval	A	2	3	5	3.17	0
C	Traffic rights and DGCA schedule approval	B	6	10	18	10.67	0.33
D	Airport slot applications (both ends)	B	4	6	10	6.33	0
E	Aircraft allocation / lease decision	B	2	4	6	4.00	4.83
F	Ground handling and fuel contracts	D	3	4	7	4.33	0
G	Crew route training	C, E	3	5	8	5.17	1.17
H	Flight schedule and fleet rotation	D, E	1	2	4	2.17	2.50
I	Fare filing and reservation loading	H, C	1	2	3	2.00	0.33
J	Marketing launch campaign	I	4	6	9	6.17	0.33
K	Sales opening and distribution	I	1	2	3	2.00	4.50
L	Station set-up and staff hiring	F	4	6	10	6.33	0
M	Proving checks and station audit	G, L	1	2	4	2.17	0
N	Dry run and inaugural flight readiness	J, K, M	1	1	2	1.17	0

Critical path: A → B → D → F → L → M → N = 29.83 weeks. Variance along it is 3.97, so $\sigma = 1.99$ weeks.

Station-readiness chain sets the 29.8-week launch

Activity-on-node network; blue = critical path A-B-D-F-L-M-N; numbers are PERT expected times



C (traffic rights), I (fares) and J (marketing) carry only 0.33 weeks of slack: a near-critical chain

route-launch network · 14 activities, critical path highlighted

Reading the slack. The airport/station chain (slots → handling contracts → station set-up) is critical, not the regulatory chain many managers would watch first. But traffic rights (C), fare filing (I) and marketing (J) have only 0.33 weeks of slack, so the regulatory–commercial chain is almost critical too. Aircraft allocation (E) and sales opening (K) have more than 4 weeks of float and can be delayed to free staff.

6.2 Probability of launching on time

Target (weeks)	Z	PERT probability	Monte Carlo probability
28	−0.92	17.9%	8.4%
30	0.08	53.3%	33.6%
32	1.09	86.2%	68.8%
34	2.09	98.2%	90.5%
36	3.09	99.9%	98.5%

PERT says a 33.1-week target gives 95% confidence; 10,000 simulation runs put the 95th percentile at 34.8 weeks. The simulated mean is 31.0 weeks, about 1.2 weeks above PERT. This is **merge bias**: near-critical paths (the regulatory chain) sometimes become the longest, which the single-path PERT formula ignores. Simulation shows activity M is on the critical path in 63% of runs, D in 52%, F and L in 50%, and C in 48% — so traffic-rights approval needs as much attention as the station set-up.

6.3 Crashing: what it costs to launch sooner

Total normal cost of the launch activities is ₹147 lakh. The LP picks the cheapest weeks to cut first.

Target launch (weeks)	Extra cost (₹ lakh)	Activities shortened
29.8	0	none
29	1.86	B, D
28	4.43	A, B, D
26	9.57	A, B, D (A and B at their limit)
24	17.91	A, B, C, D
22	27.72	A, B, C, D, F, I, M
20	48.48	Almost every activity

The curve is convex: the first two weeks cost about ₹2.2 lakh each, the last weeks over ₹13 lakh each. Below 26 weeks the regulatory approval (C) must be crashed as well, which in practice depends on the regulator and may not be buyable at any price — a real limit of the linear cost assumption.

7. Solution Methodology Across the Papers

The papers solve the network in four ways, moving over time from hand calculation to simulation and optimisation, and most validate by comparing the model's schedule with what actually happened.

7.1 Solution techniques

Technique	How it works	Papers
Forward/backward pass (classic CPM)	Hand or spreadsheet calculation of ES, EF, LS, LF and slack	Summers; Dimas; Daffa et al.; Johi & Khalaf
PERT three-time estimate + normal probability	t_e and σ per activity, Z-score for a target date	Dimas; Nahendra et al.; Nurdin et al.; Avief et al.
Crashing / LP and integer programming	Minimise cost or staff subject to network constraints	Nahendra et al.; Nurdin et al.; Al-Bazi et al.; Číleček & Teichmann; Kuster et al.
Monte Carlo / stochastic simulation	Sample durations thousands of times, record critical paths	Wu & Caves; Ersahin et al.; San Antonio et al.; Nursanti et al.; Avief et al.
Fuzzy CPM and critical chain	Fuzzy time numbers; shared project buffers instead of task padding	Atli & Kahraman; Kulkarni et al.

7.2 Software and tools

- **Project software:** Microsoft Project (Nursanti et al.; Avief et al.), Primavera P6 (Johi & Khalaf).
- **Optimisation:** IBM ILOG OPL (Al-Bazi et al.), LP/MILP solvers (Nurdin et al.; Číleček & Teichmann).



- **Simulation:** @Risk (Avief et al.), Arena (Nursanti et al.), custom Monte Carlo models (Wu & Caves; San Antonio et al.).
- **Statistics:** SPSS for paired t-tests (Avief et al.).
- **Real-time systems:** rule-based software on mobile devices over GPRS (Makhloof et al.).
- **This study:** Excel formulas for PERT/CPM and probability; Python (SciPy HiGHS) for the crashing LP and NumPy for 10,000 simulation runs.

7.3 How solutions were analysed and validated

1. **Against company records.** Daffa et al. compared CPM time (20.47 days) with the company plan (21.73 days); Avief et al. compared predictions with 12 real overhauls using mean absolute error, a paired t-test ($p = 0.003$) and leave-one-out cross-validation.
2. **Against observations.** Wu & Caves compared simulated punctuality with observed turnarounds; Kulkarni et al. used a survey and field observation.
3. **Software cross-check.** Johi & Khalaf confirmed their hand-calculated 478 days in Primavera.
4. **Scenario and sensitivity analysis.** San Antonio et al. tested three load factors and two turnaround designs; Avief et al. ranked risk factors with a tornado chart.
5. **Test-case implementation.** Samaranayake et al. ran their structure on a Qantas test case.

In this study the Excel model was checked by recalculating every formula and comparing it with the independent Python computation (same critical path, $T = 29.83$ weeks).

8. Critical Analysis

The evidence consistently shows that managing the critical path shortens aviation projects — the six papers with before/after figures report a median improvement of about 24% — but the classic single-path PERT model is too optimistic when several paths are close to critical, which is exactly the case in a route launch.

8.1 Key findings

1. **Real time savings.** Hawk overhaul 283 → 31 days (Nursanti et al.), A02-check 6,199 → 4,090 minutes (Nurudin et al.), Gebe Airport 34 → 32 weeks (Nahendra et al.), C-check 21.73 → 20.47 days (Daffa et al.).
2. **Plans are often over-confident.** The C-295 plan had a 31% chance of being met (Dimas); deterministic CPM missed overhaul durations by 17.6 days on average (Avief et al.).
3. **The critical path moves under uncertainty.** The baseline overhaul path stayed critical in only 38% of simulation runs (Avief et al.); in our route model the station chain is critical in about half the runs and traffic rights in 48%.
4. **Float is a resource.** Čileček & Teichmann removed a whole staff group by using float; in our model aircraft allocation and sales opening have over 4 weeks of float.

8.2 Impact and implications for airline route planning

- A launch date should be quoted with a probability, not a single number. Announcing week 30 gives only a one-in-three chance by simulation; week 34 gives about 90%.
- Management attention should follow the criticality index, not just the deterministic critical path: both the station chain and the regulatory chain need weekly tracking.
- The cheapest way to launch sooner is to compress early planning (demand study, board approval, slot applications), not regulatory approval.
- Turnaround and maintenance studies supply the inputs a route planner needs — minimum ground time and aircraft availability — so the launch network links to those operational models.

8.3 Strengths of the approach

- Simple, visual and easy to explain to non-specialists; works in Excel.
- Gives four decision outputs: launch date, critical tasks, probability and crash cost.
- Scales from an 8-activity turnaround to an 85-activity airport project.
- Extends naturally to LP, simulation and resource models, as the literature shows.

8.4 Limitations and assumptions

- **Merge bias:** PERT ignored near-critical paths and understated the mean launch time by 1.2 weeks and the 95% target by 1.7 weeks.
- **Independence and beta assumptions** rarely hold — regulatory delays tend to affect several tasks at once.
- **Linear crash costs** are unrealistic for approvals that cannot be bought.
- **Unlimited resources** — most papers ignore shared crews, engineers or hangar slots.
- **Data quality:** many studies are single cases with small samples ($n = 12$ in Avief et al.), and some report errors — Daffa et al. state 0.057% efficiency where their own figures give 5.8%, and Avief et al. give both 57.95% and 15.4% for the same improvement.
- **Our case is hypothetical;** its numbers illustrate the method and should be replaced with an airline's own estimates.

8.5 Possibilities for extension

1. Use Monte Carlo simulation as standard, and report the criticality index alongside the critical path.
2. Add resource constraints (RCPSP) for shared planning, crew-training and station teams.
3. Use fuzzy or Bayesian-updated estimates where history is thin (new markets, new regulators).
4. Model several route launches together as a multi-project portfolio with critical-chain buffers.
5. Link the launch network to a route-selection model, so that the choice of route and the time to launch it are decided together.

9. Conclusion

PERT/CPM is a sound and practical way to plan the launch of a new airline route, provided its single-path probability is backed by simulation. Across 20 studies spanning 1965–2026, critical-path methods cut maintenance downtime, sharpened turnaround schedules and gave realistic completion odds for airport works. Applied to a 14-activity route launch, the model finds an expected launch in 29.8 weeks along the station-readiness chain, shows that the regulatory chain is almost equally critical, and prices each week of acceleration. Simulation moves the realistic expectation to 31 weeks and the 90% date to about 34 weeks — the difference between a launch promise that is likely kept and one that is likely broken. The main lesson for airline planners is to quote launch dates with probabilities, track every near-critical chain, and buy time first where it is cheapest.

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