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Research Task in Air Transport and Logistics

Topic 03: Evaluation and Comparison of Alternative Path Planning Methods on Ground Risk Maps

Background

For safe UAV operations, route planning must balance path length against induced ground risk. In previous work, a modified A* algorithm (both single- and bi-directional) with a risk heuristic and a hard constraint on the Target Level of Safety (TLS) has been developed [1]. This approach already delivers feasible and safety-compliant routes, but can be computationally expensive when operating on dense risk maps or fine spatial resolutions. To improve computational efficiency while maintaining acceptable safety performance, different algorithmic principles can be explored. Examples include:

- Hierarchical or multi-resolution search, where a coarse route is found quickly and then locally refined.
- Gradient- or potential-based methods, that iteratively shift an initial straight-line path toward lower-risk regions until TLS compliance is achieved.
- Sampling-based algorithms (e.g., RRT*, PRM) adapted to risk-weighted cost functions.
- Constrained shortest-path methods that explicitly handle dual-objective optimization (e.g., minimizing length under a hard risk limit).

This task aims to compare alternative planning approaches against the current A* baseline in terms of runtime, path quality, and TLS compliance, and to analyze their suitability for real-time or onboard risk-aware navigation.

Tasks

1. **Method selection & setup**
   Review path planning algorithms to select at least two alternatives to the A* relevant for risk-constrained routing. Define how risk and TLS are incorporated into the cost or feasibility criterion, and how each method explores the search space.
2. **Integration with the risk map**
   Use the provided 2-D ground-risk map (CSV + metadata) as the environment. Implement a consistent function for accumulated risk along the path (e.g., distance × local risk) and a check for TLS compliance.
3. **Scenario definition**
   Create a representative set of start–goal pairs across different map regions and distances. Use the same set for all methods to enable fair comparison.
4. **Evaluation**
   For each method, compute:
   a) Path length,
   b) Accumulated (induced) risk,
   c) TLS feasibility, and
   d) Computation time.

Compare average results, variances, and sensitivity to grid resolution or weighting parameters.

5. **Discussion**
   Discuss algorithmic trade-offs between accuracy and runtime and summarize under which conditions each approach is preferable. Highlight potential hybrid strategies or extensions for future work (e.g., coarse-to-fine refinement, local smoothing, or risk-gradient post-processing).

Implementation Note
MATLAB or Python may be used. All methods should use a common evaluation framework to compute path length, accumulated risk, and TLS compliance. Document parameters and assumptions transparently in the report.

Deliverables
- **Research paper** (10–12 pages, ≥20 references) submitted as PDF in OPAL.
- Three **presentations** according to course schedule.
- **Code repository** (e.g., Git) containing the implemented planners and evaluation scripts.

Milestones & Workload
- **Initial**: Scope + Literature research on search and optimization algorithms; screening and pre-selection of candidate methods for implementation.
- **Mid-term:** planners implemented and tested on initial scenarios.
- **Final:** complete evaluation, sensitivity analysis, and discussion.
  Team of five; total workload ~**150 hours per student** (literature, implementation, analysis, and writing).

[1] H. Braßel, T. Zeh, M. Lindner und H. Fricke, „Risk-Aware UAV Trajectory Optimization Using Open Urban GIS Data and Target Level of Safety Constraints.," 2025.