Phase C
Hillink Applicability Index – HAI

Purpose

The weights used in the MCDA model are not treated as fixed or self-evident values. They are defined through a structured weighting process and tested through sensitivity analysis.

In the first version, weights are assigned according to the project's theory of change: physical barriers and transport burden receive higher importance because Hillink is specifically designed to reduce last-segment cargo effort. Technical feasibility and regulatory/environmental feasibility work both as weighted criteria and as minimum eligibility thresholds.

In later stages, these weights can be refined through expert judgment, community consultation, or pairwise comparison methods such as the Analytic Hierarchy Process (AHP). The robustness of the model is tested by checking whether route rankings remain stable under alternative weighting scenarios.

$$\mathrm{HAI}_i = 100 \cdot (0.30B_i + 0.25L_i + 0.15P_i + 0.20T_i + 0.10R_i)\,.$$

$$B_i = 0.35\widehat{H}_i + 0.25\widehat{S}_i + 0.25\widehat{N}_i + 0.15\widehat{A}_i.$$

$$\mathrm{VLB}_i = HH_i \cdot q_i \cdot f_i \cdot H_i.$$

$$L_i = \widehat{\mathrm{VLB}}_i, \qquad P_i = \widehat{HH}_i, \qquad T_i = \frac{T_{\mathrm{raw},i}}{25}, \qquad R_i = 1 - \frac{\mathrm{Risk}_{\mathrm{raw},i}}{25}.$$

$$\mathrm{Decision}_i = \begin{cases} \text{Do not advance,} & T_i < 0.50, \\ \text{Do not advance / major adaptation,} & R_i < 0.40, \\ \text{Advance,} & \mathrm{HAI}_i \geq 80, \\ \text{Advance with adaptations,} & 60 \leq \mathrm{HAI}_i < 80, \\ \text{Do not advance,} & \mathrm{HAI}_i < 60. \end{cases}$$

Why MCDA

MCDA allows different types of evidence—physical, social, technical, environmental, and institutional—to be converted into comparable scores and combined into a structured decision.

Unit of Analysis

The model evaluates candidate routes, not the entire neighborhood. A candidate route is defined as the path between a vehicle-accessible point and a group of households that currently depends on manual transport of essential goods.

Unit	Definition
Candidate route	Path from a vehicle-accessible road to a household cluster.
Decision	Advance, advance with adaptations, or do not advance.
Scale	Route-level, not city-level.

Required Inputs

Each route is described through a minimum set of inputs related to terrain, demand, population served, technical feasibility, and implementation risk.

Input	Meaning	Source
H	Vertical elevation gain	DEM, GPS, or field measurement
S	Average slope	DEM or field estimate
N	Number of steps	Field count, video, or estimate
A	Distance to vehicle-accessible road	OSM, QGIS
HH	Households served	Field count, satellite imagery, WorldPop/GHSL
q	Average load per trip	Phase B or scenario assumption
f	Trips per week	Phase B or scenario assumption
T_{raw}	Technical checklist score	Field checklist
Risk_{raw}	Regulatory/environmental risk score	Municipality, community leaders, field observation

Core Metric: Vertical Load Burden

The central burden metric is the Vertical Load Burden, which estimates the amount of cargo that must be moved vertically each week by the households served by a route.

$$\text{VLB}_i = HH_i \cdot q_i \cdot f_i \cdot H_i.$$

Term	Meaning
HH_i	Households served by route i.
q_i	Average kilograms per trip.
f_i	Trips per week.
H_i	Vertical elevation gain.

Unit:

$$\text{kg} \cdot \text{m/week}$$

This metric is useful because it combines population served, cargo weight, transport frequency, and vertical terrain difficulty into one interpretable measure.
It connects engineering analysis with social impact by showing how the domestic transport of essential resources can affect health, time use, gendered labor, and household economy.

Normalization

Since the model combines variables with different units, all indicators are normalized into a common 0–1 scale before aggregation.

For variables where a larger value means higher priority:

$$\widehat{x}_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}.$$

Examples include elevation gain, number of steps, access distance, households served, and Vertical Load Burden.

For variables where a larger value means higher risk or lower feasibility:

$$\widehat{x}_i = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}}.$$

For a risk checklist scored from 0 to 25:

$$R_i = 1 - \frac{\mathrm{Risk}_{\mathrm{raw},i}}{25}.$$

The purpose of normalization is to make it possible to compare meters, kilograms, households, steps, and risk within the same model.

Subscores

Physical Barrier Score

The Physical Barrier Score measures the territorial difficulty of the route. Elevation and slope receive higher importance because they directly increase the effort required to move cargo manually.

$$B_i = 0.35\widehat{H}_i + 0.25\widehat{S}_i + 0.25\widehat{N}_i + 0.15\widehat{A}_i.$$

Variable	Meaning
$\widehat{H}$	Normalized elevation gain.
$\widehat{S}$	Normalized slope.
$\widehat{N}$	Normalized number of steps.
$\widehat{A}$	Normalized access gap.

Load Burden Score

The Load Burden Score captures the aggregate weekly cargo effort imposed by the route.

$$L_i = \widehat{\mathrm{VLB}}_i.$$

Population Served Score

The Population Served Score estimates the local scale of benefit by measuring how many households could be served by the route.

$$P_i = \widehat{HH}_i.$$

Technical Feasibility Score

The Technical Feasibility Score prevents socially urgent but technically unsafe routes from advancing automatically. It works as a safety and installability filter before any pilot implementation.

$$T_i = \frac{T_{\mathrm{raw},i}}{25}.$$

Item	**Score**
Route width	**0–5**
Route continuity	**0–5**
Anchoring points	**0–5**
Loading/unloading area	**0–5**
Manageable obstruction risk	**0–5**

Regulatory and Environmental Feasibility Score

The Regulatory and Environmental Feasibility Score controls for permission uncertainty, construction restrictions, corrosion exposure, local adaptation requirements, and maintenance conditions before the route advances to a pilot stage.

$$R_i = 1 - \frac{\text{Risk}_{\text{raw},i}}{25}.$$

Risk	**Score**
Municipal permission uncertainty	**0–5**
Unclear public/private route status	**0–5**
Corrosion or humidity exposure	**0–5**
Maintenance uncertainty	**0–5**
Misuse or vandalism risk	**0–5**

Hillink Applicability Index

The final Hillink Applicability Index combines the five subscores into a single route-level score.

$$\text{HAI}_i = 100 \cdot (0.30B_i + 0.25L_i + 0.15P_i + 0.20T_i + 0.10R_i)\,.$$

Component	Weight	Role
B_i **Physical Barrier**	30%	Confirms territorial need.
L_i **Load Burden**	25%	Estimates cargo effort.
P_i **Population Served**	15%	Measures local scale.
T_i **Technical Feasibility**	20%	Ensures installability.
R_i **Risk Feasibility**	10%	Controls institutional and environmental risk.

The weights are not treated as absolute truths. They reflect the project's theory of change: Hillink is most relevant where physical barriers and cargo burden are high, but it can only advance where technical and institutional feasibility are acceptable.

Decision Rules

The model does not rely only on the final HAI score. It also applies minimum feasibility thresholds to avoid recommending unsafe or institutionally blocked routes.

$$T_i < 0.50 \Rightarrow \text{Do not advance.}$$

$$R_i < 0.40 \Rightarrow \text{Do not advance or require major adaptation.}$$

$$B_i < 0.40 \Rightarrow \text{Low applicability.}$$

After applying the minimum thresholds, the final score is interpreted as follows:

HAI range	Decision
HAI ≥ 80	Advance.
$60 \leq$ HAI < 80	Advance with adaptations.
HAI < 60	Do not advance at this stage.

This prevents Hillink from advancing to pilot based only on social need. A route must combine relevant burden with minimum technical safety, institutional feasibility, environmental durability, and maintenance capacity.

Robustness Check

Because initial weights and some inputs may be estimated, the model is tested through sensitivity analysis. The goal is to avoid depending on a single arbitrary set of weights.

Scenario	What changes
Base	Default weights.
Social priority	Higher weight for load burden and population served.
Engineering safety	Higher weight for technical feasibility and risk feasibility.
Conservative	Higher penalty for regulatory and maintenance uncertainty.

If the same route remains highly ranked under different weighting scenarios, the decision is considered more robust. If rankings change significantly, the route requires further field validation before pilot selection.

Final Output

The final output of Phase C is a structured route-level decision based on the HAI score and the minimum rules for safety, permission, and maintenance.

Result	Meaning	Next step
Advance	The route has high need and sufficient feasibility.	Move to community validation and pilot design.

Result	Meaning	Next step
Advance with adaptations	The route is promising but has restrictions.	Adjust material, route alignment, anchoring, permission, or maintenance plan.
Do not advance at this stage	The route is not suitable at this stage.	Select another route or repeat the diagnosis.

Example

Route	HAI	Decision	Main reason	Required adaptation
R01	82	Advance	High physical barrier, high load burden, and acceptable feasibility.	Minor corrosion protection.
R02	68	Advance with adaptations	Strong need, but weak anchoring and permit uncertainty.	Redesign anchoring and consult the municipality.
R03	44	Do not advance	Low technical feasibility and high obstruction risk.	Select an alternative route.

Routes classified as *Advance* or *Advance with adaptations* move to Phase D, where the decision is validated with community representatives, maintenance responsibilities are assigned, and rules of use are defined before any pilot installation.