



(RESEARCH ARTICLE)



BEYOND PROXIMITY: A MULTI-FACTOR FRAMEWORK FOR MATCHING RECOVERABLE MATERIALS WITH CIRCULAR RESOURCE OPPORTUNITIES

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ABSTRACT

Recovering materials for reuse or recycling depends on connecting them with the right destination, not just the nearest one. GIS is widely used to site recycling infrastructure and measure how accessible it is, but proximity alone does not tell us whether a nearby facility can actually use a given material. This study proposes a Multi-Factor Circular Matching Framework (MFCMF) that screens candidate destinations by material acceptance, then ranks the remaining options by distance and quantity fit. Three allocation methods are compared: picking the nearest destination regardless of material fit, picking the nearest destination that accepts the material, and MFCMF's full multi-factor ranking. Comparing these three separately shows how much of the difference in outcomes comes from screening out incompatible destinations versus from also weighing quantity fit. The framework is demonstrated through twelve illustrative scenarios, constructed to be broadly realistic and to span the range of outcomes the framework can produce, not as an empirical sample. The demonstration shows that quantity compatibility can alter destination selection even after material compatibility has already been enforced, illustrating the distinct analytical role of quantity fit beyond compatible proximity alone.

Keywords: Circular Economy; GIS; Resource Recovery; Material Matching; Spatial Analysis; Industrial Symbiosis; Multicriteria Decision Analysis

1 INTRODUCTION

Materials that could be reused or recycled often end up disposed of anyway, even when a suitable recovery option exists somewhere nearby. Part of the reason is spatial: a material is generated in one place, and recovery options are scattered elsewhere, so distance and access shape whether recovery actually happens. GIS has long supported this side of the problem, siting facilities, mapping accessibility, optimizing collection routes.

But proximity is not the same as compatibility. A material generator two miles from one facility and eight miles from another will, under a pure-distance model, always be routed to the closer one, even if that facility does not accept the material or cannot handle the quantity involved. The farther facility may be the only real option.

1.1 Proximity ≠ Compatibility.

This gap matters more as circular economy systems grow beyond a single collection network into a web of generators, processors, reuse organizations, and recyclers. Industrial ecology research has shown for decades that useful exchanges between organizations depend on more than being nearby (Frosch & Gallopoulos, 1989; Boons et al., 2011), and a growing set of digital tools now exist specifically to help identify which exchanges are viable (Yeo et al., 2019; Akrivou et al., 2021), a point we return to in Section 2.

This study introduces the Multi-Factor Circular Matching Framework (MFCMF), a proof-of-concept that starts with three factors: whether a destination accepts the material, how far away it is, and how well its capacity matches the quantity available.

Two questions guide the work:

- Can material fit, distance, and quantity fit be combined into a simple, reproducible scoring method?
- When compatibility is factored in, how often, and why, does the preferred destination change compared to picking the nearest option?

On that second question, "nearest option" is ambiguous by itself, so this study separates it into two versions: the nearest destination period, and the nearest destination that actually accepts the material. Comparing all three methods, naive nearest, compatible nearest, and full MFCMF, makes it possible to say specifically how much of any difference in outcomes comes from filtering out invalid destinations versus from weighing quantity fit on top of that.

The framework is demonstrated using twelve illustrative scenarios; the geography is kept generic, since it is not a structural requirement of the method. The scenarios are constructed by hand, not sampled from real data, and are designed to walk through the different ways the three methods can agree or disagree. The goal here is to show the method works as intended, not to characterize any specific real-world recovery system.

2 BACKGROUND

2.1 Locating Infrastructure vs. Routing Materials

GIS has mainly answered two questions in waste management: where should recovery infrastructure go (facility siting), and how accessible is it once built (proximity and accessibility analysis) (Ghiani et al., 2014; Rada et al., 2013). A prior study of New Haven County, Connecticut used GIS this way, identifying optimal locations for recyclable-waste drop-off centers based on the spatial distribution of demand (Bashiru, 2023).

Neither question, though, tells us whether a specific destination can actually use a specific material. Research on accessibility more broadly has found that people don't simply choose the closest option, since destination quality and fit substantially change the picture (Macfarlane et al., 2022). The same applies here: knowing a facility is close says nothing about whether it accepts the material or has room for it.

2.2 Industrial Symbiosis: It Takes More Than Proximity

A foundational industrial ecology formulation proposed that one organization's waste output could serve as another's input (Frosch & Gallopoulos, 1989), an idea industrial symbiosis has built on since (Ehrenfeld & Gertler, 1997). Later work has emphasized that realizing these exchanges depends on more than physical proximity, as successful symbiosis also requires ongoing social, organizational, and institutional coordination among the parties involved (Boons et al., 2011; Lombardi & Laybourn, 2012).

This same logic extends past classic industrial symbiosis to any network of generators, processors, and recovery organizations, circular or otherwise: proximity narrows the search, but it does not confirm a viable match.

2.3 Existing Matching Tools, and What This Study Adds

Two related bodies of work already tackle parts of this problem, and it is worth being specific about how MFCMF relates to them.

Industrial symbiosis matching platforms. A systematic review of tools built to support industrial symbiosis found a fragmented landscape, with most tools handling one piece of the matching problem (identifying a possible exchange, or evaluating one) rather than a complete pipeline from eligibility to ranking (Yeo et al., 2019). A separate systematic review of the data points these platforms actually rely on found that location/distance, material or waste type, and

quantity are consistently among the most important fields used to identify viable synergies (Akrivou et al., 2021), the same three starting factors MFCMF uses, though existing platforms typically combine them through more complex, less transparent matching logic than the simple screen-then-rank approach used here. MFCMF shares the basic idea of screening candidates and then ranking them by weighted factors, but is built specifically for material-recovery matching rather than firm-to-firm industrial exchanges, and, as a proof-of-concept, keeps the factor set small and fully transparent rather than learned or database-driven.

GIS-based multicriteria decision analysis (GIS-MCDA). Combining multiple weighted factors into a single spatial suitability score is a well-established technique, most often used for siting decisions such as where something should go (Malczewski, 2006). MFCMF borrows this same weighted-combination logic, but applies it to a different question: not where infrastructure should be sited, but which of the *already-sited* destinations best fits a *specific* source. The eligibility screen (Section 3.3) is also a hard constraint rather than another weighted factor, which keeps material compatibility from being "outvoted" by a short distance, something a standard weighted-overlay approach would not enforce on its own.

Put together, the contribution here is narrow but specific: a small, transparent, reproducible scoring method aimed at source-to-destination matching for material recovery, sitting between facility-siting tools (which don't consider the material at all) and industrial-symbiosis platforms (which are built for firm-to-firm exchanges, not individual recovery destinations).

3 MATERIALS AND METHODS

3.1 Study Design

This is a proof-of-concept demonstration, not an empirical study. Twelve source-opportunity scenarios were constructed by hand, not sampled from real data, to walk through the ways three allocation methods can agree or disagree. Each scenario has one material source and two or three candidate destinations.

Three allocation methods are compared for every scenario:

- Naive Proximity, pick whichever destination is closest, whether or not it accepts the material.
- Compatible Proximity, pick whichever destination is closest *among those that accept the material*.
- MFCMF, among destinations that accept the material, pick the one with the best combined score for distance and quantity fit.

Comparing Naive → Compatible isolates the effect of the material screen alone. Comparing Compatible → MFCMF isolates the effect of quantity fit, on top of a baseline that already accounts for material compatibility. This avoids crediting MFCMF for differences that are really just a byproduct of excluding a destination that could never have accepted the material in the first place.

3.2 Scenario Construction

Each scenario source has a material type (paper/cardboard, plastics, or metals) and a size category (Small, Medium, or Large). Each candidate destination has a distance from the source, a Yes/No for whether it accepts that material, and its own size category. Distances are illustrative, scaled to be plausible for a small, regional-scale recovery network (roughly half a mile to about 12 miles).

The twelve scenarios were built to cover specific situations, not to reflect any statistical sample:

Table 1: What each scenario is built to show.

Scenario	Material	What it demonstrates
S1	Cardboard	Quantity fit overturns a proximity-only pick, even after material screening
S2	Plastics	Material screening alone overturns a nearer, incompatible pick
S3	Metals	All three methods agree, the nearest option is already the best one
S4	Cardboard	Material screening overturns a nearer, incompatible pick (one eligible alternative)
S5	Plastics	No destination accepts the material, unmatched under both stricter methods
S6	Metals	Two destinations at nearly the same distance; quantity breaks the tie, no method disagrees

S7	Cardboard	Outcome depends on how distance and quantity are weighted (see Section 4.5)
S8	Plastics	Everything aligns, nearest is also the best quantity match
S9	Metals	Equal quantity mismatch on both sides, so distance alone decides
S10	Cardboard	Material screening overturns a nearer, incompatible pick (three candidates)
S11	Plastics	Two nearly-equidistant destinations; quantity fit tips a close call
S12	Metals	Only one destination exists at all, every method is forced to the same answer

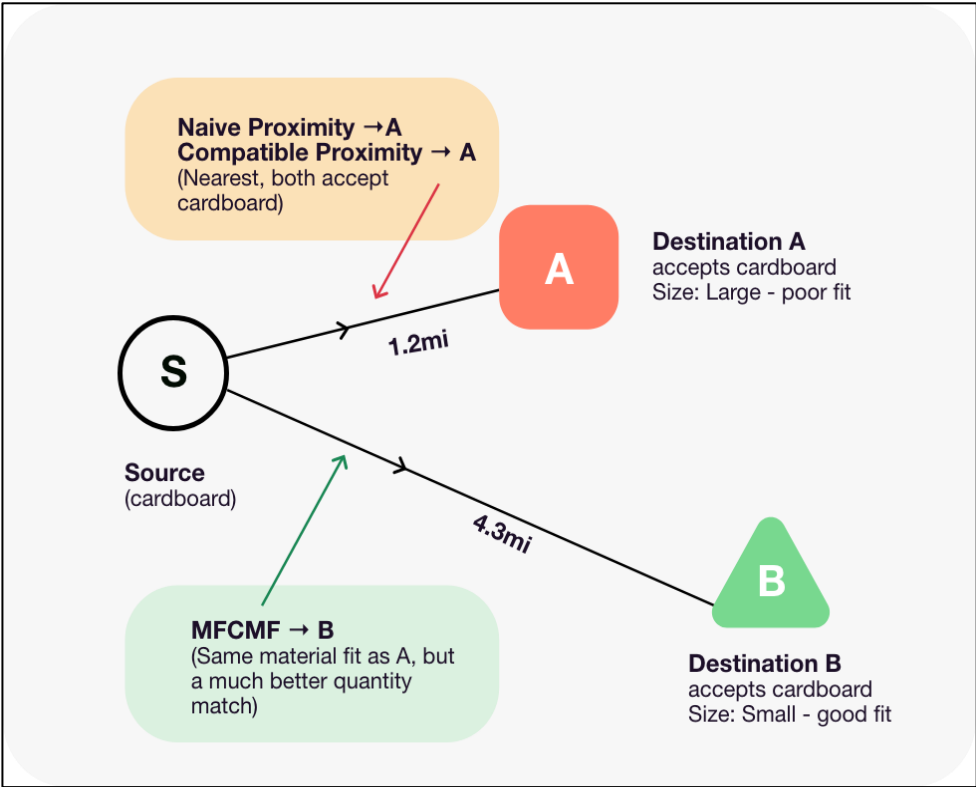


Figure 1: A simplified illustration of Scenario S1: both candidate destinations accept the source's material, so Naive Proximity and Compatible Proximity both select the nearer Destination A. Destination A is a poor quantity match, however, while the farther Destination B is a good one, so MFCMF selects B instead, isolating the effect of quantity fit alone.

1.3 Material Fit

The first check is simple: does the destination accept the material?

Accepts = Yes or No

A No removes that destination from consideration entirely, so distance and quantity are never evaluated for it. This is a hard cutoff, not one more factor to be weighed: a very close destination that cannot take the material should never win just because it's close.

1.4 Distance Score

Among the destinations that passed the material check, each is scored by how close it is *relative to the others still in the running*, not by raw distance.

Let distance be how far a destination is from the source, and farthest distance be the distance of the farthest destination still eligible for that source.

Distance Score = 1 – (distance ÷ farthest distance)

The closest eligible destination scores near 1; the farthest scores 0. Because this is a ratio, it works the same whether distances are measured in miles or kilometers.

A limitation of this approach is that the distance score is relative to whichever destinations happen to be in the comparison set. A single unusually far destination pulls everyone else's score upward, since it resets what counts as "far." A fixed distance cutoff (e.g., a score of 0 past 10 miles, regardless of what else is being compared) is a reasonable alternative for future versions, at the cost of needing to justify a specific threshold.

1.5 Quantity Score

Sources and destinations are each labeled Small, Medium, or Large.

- Same size category → Quantity Score = 1.0
- One category apart → Quantity Score = 0.5
- Two categories apart → Quantity Score = 0.0

This treats "quantity" as a rough size match, not literal capacity. A real destination's capacity is usually a *rate*, tons per day or per year, while a source's quantity is often a one-time or per-pickup amount. The two aren't strictly the same kind of number, and future versions should convert both to comparable units (e.g., expected pickups per year against annual intake capacity) rather than relying on size-category labels alone.

1.6 Combined Score

Once a destination has passed the material check, it gets one combined score:

Match Score = (Distance Score + Quantity Score) ÷ 2

This is a plain average, equivalent to weighting distance and quantity equally (50/50). Equal weighting is a transparent starting point, not a claim that the two factors matter equally in practice; Section 4.5 tests how much the results change under different weightings.

Whichever eligible destination has the highest Match Score is selected under MFCMF. Figure 2 summarizes the full scoring pipeline described in Sections 3.3 through 3.6.

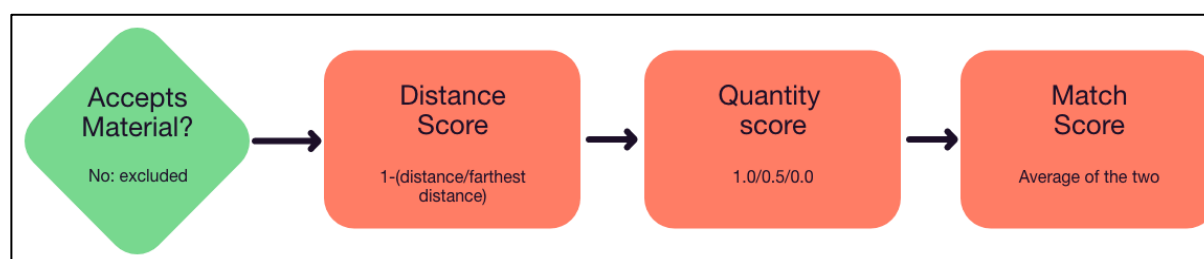


Figure 2: The MFCMF scoring pipeline: a hard material-eligibility gate, followed by a Distance Score and a Quantity Score that are averaged into a single Match Score.

1.7 Comparing the Three Methods

For each scenario, the three methods (Naive Proximity, Compatible Proximity, MFCMF) each produce a pick. Two comparisons matter:

Naive → Compatible disagreement rate = share of scenarios where adding the material screen changes the pick

Compatible → MFCMF disagreement rate = share of scenarios where adding quantity fit changes the pick, given that material screening is already applied

Scenarios where no destination accepts the material (see S5) have no valid pick under Compatible Proximity or MFCMF and are reported separately rather than folded into either rate.

A sensitivity check re-runs the Match Score with distance and quantity weighted 70/30 and 30/70 instead of 50/50, to see how much the picks depend on that choice.

4 RESULTS

4.1 Overview

The twelve scenarios include four each of cardboard, plastics, and metals sources, with 27 total source-destination pairs. Three pairs were deliberately built as "close but incompatible", a nearer destination that does not accept the material (S2, S4, S10), to test whether the material screen catches them. One scenario (S5) has no compatible destination at all.

4.2 Naive Proximity

Picking the nearest destination with no regard for material fit picked an *incompatible* destination in 3 of 12 scenarios (25%), exactly the three built for that purpose (S2, S4, S10). This is the baseline problem the material screen exists to fix.

4.3 Compatible Proximity vs. MFCMF

Restricting to destinations that accept the material and picking the closest one (Compatible Proximity) resolves those three cases. But it does not fully match MFCMF: among the 11 scenarios where a compatible destination exists, MFCMF picks differently from Compatible Proximity in 2 cases (S1, S11), both driven purely by quantity fit, since material compatibility is already identical between the two methods at that point.

Table 2: Where the three methods agree and disagree.

Comparison	Disagreements	Rate	Cause
Naive → Compatible	3 of 11 matched scenarios	27.3%	Material screening alone (S2, S4, S10)
Compatible → MFCMF	2 of 11 matched scenarios	18.2%	Quantity fit alone (S1, S11)
Naive → MFCMF (combined)	5 of 11 matched scenarios	45.5%	Both effects together

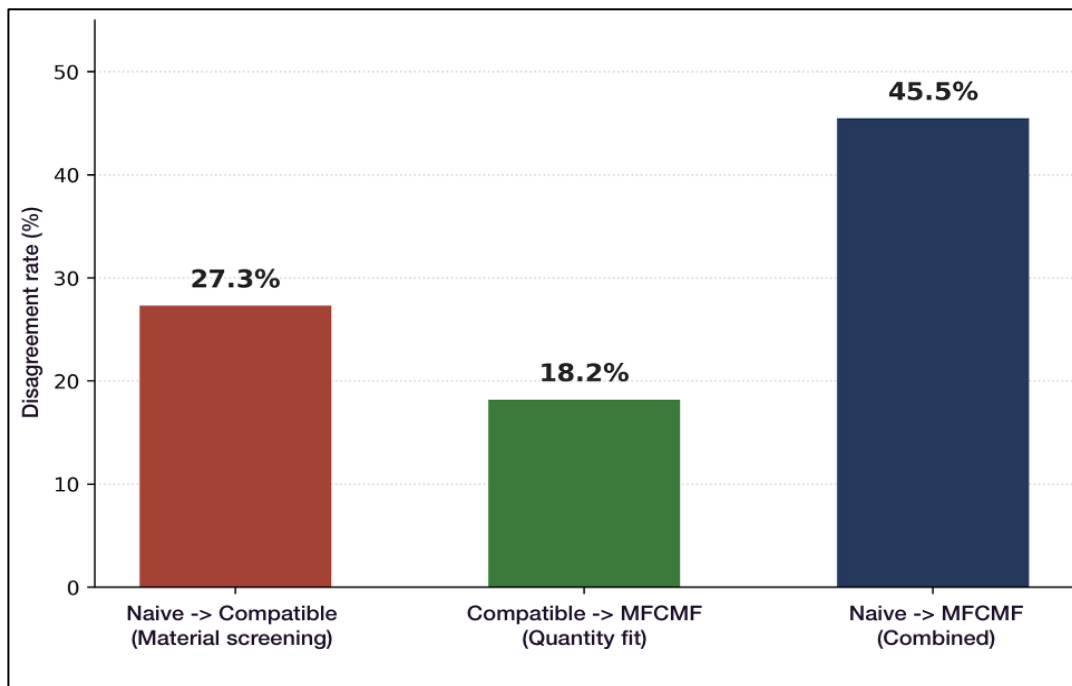


Figure 3: Disagreement rates across the three method comparisons, decomposed into the material-screening effect, the quantity-fit effect, and their combination.

Splitting the combined disagreement, 5 of 11 scenarios, or 45.5%, into these two stages shows that quantity fit is doing separate, identifiable work of its own, not merely a downstream consequence of the material screen. This demonstrates that MFCMF provides additional discrimination beyond a "closest facility that will accept the material" rule.

Table 3: Average distance and quantity fit for each method (11 matched scenarios).

Measure	Naive Proximity	Compatible Proximity	MFCMF
Mean distance	2.4 mi	2.6 mi	3.7 mi
Destinations that accept the material	72.7% (8 of 11)	100%	100%
Mean quantity fit	0.73	0.73	0.91

Where MFCMF picked differently from Compatible Proximity (S1, S11), it traded an average of 2.3 additional miles for a 40-percentage-point increase in quantity fit. Whether that trade is worth it in practice is a cost/logistics question outside this proof-of-concept's scope. These results demonstrate the existence of this tradeoff without establishing that the additional travel distance necessarily produces a preferable outcome.

4.4 Scope of These Numbers

These figures describe the twelve constructed scenarios, not a real recovery system. The scenario set was deliberately built to include a mix of agreement and disagreement cases, plus edge cases (S5's unmatched source, S12's single-option source), so none of these percentages should be read as an estimate of how often this would happen with real facilities and real material flows.

4.5 Sensitivity to Weighting

At the 50/50 baseline, shifting the weighting in either direction changed exactly one pick each way: 70/30 (favoring distance) reverted S1 back to the Compatible Proximity pick, and 30/70 (favoring quantity) changed S7's pick. The other nine scenarios were unaffected by either shift. This suggests the method's picks are not highly sensitive to moderate reweighting, as most scenarios were decisive enough that a shift in emphasis didn't change the answer, but the method is not weighting-proof either, which is expected and intended.

5 DISCUSSION

The central distinction this paper makes is between being accessible and being usable: a facility search can be extended to include one more step past siting and proximity.

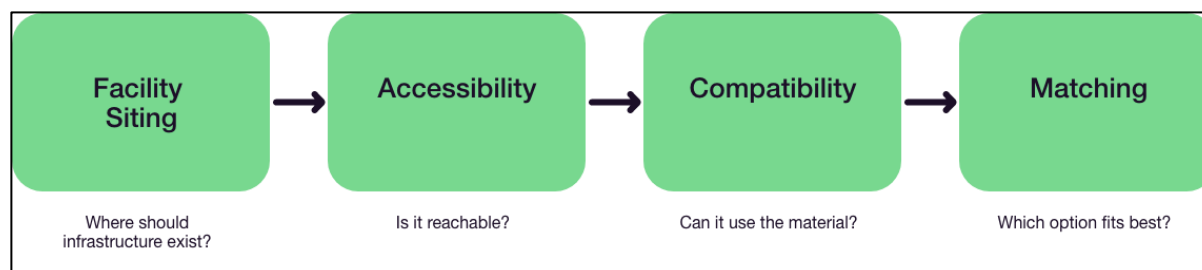


Figure 4: The four-stage progression from infrastructure siting to individual source-to-destination matching. GIS has traditionally addressed the first two stages; MFCMF adds the latter two.

Siting asks where infrastructure should exist; accessibility asks whether it's reachable; compatibility asks whether it can actually use the material; matching picks the best fit among the options that pass that test. Conventional GIS applications in waste-management planning have often emphasized the first two steps (Bashiru, 2023); MFCMF operationalizes the latter two for source-to-destination material recovery.

What MFCMF is a first version of. The three-factor version tested here is deliberately narrow. A fuller matching system would also weigh material quality, timing, logistics, cost, and environmental impact, since the framework is built to be extended that way rather than to stay fixed at three factors. The implementation presented here therefore represents an initial version of the broader MFCMF architecture: MFCMF (general framework) → current implementation (material + distance + quantity) → future versions (+ quality, timing, logistics, cost, environmental impact). The three-factor version demonstrates the mechanics; it is not a claim that these three factors are sufficient on their own.

On distance increasing. MFCMF sometimes recommends traveling farther than the nearest compatible option (Section 4.3). That is not automatically a bad outcome, since a somewhat farther destination that actually fits the quantity may

be more viable overall, but added distance does carry real transportation cost and emissions that this proof-of-concept does not price in. A useful next step is adding a distance penalty or hard cutoff, so the framework can flag when a quantity-driven detour has gone past the point of being worth it.

Where this sits relative to existing tools. As discussed in Section 2.3, this is not the first attempt to move matching beyond simple proximity, given that industrial symbiosis platforms already rely on distance, material type, and quantity as key matching fields (Akrivou et al., 2021), and GIS-MCDA has used weighted combination for siting decisions for years (Malczewski, 2006). What MFCMF adds is narrower: a hard material-eligibility gate ahead of the weighting step, applied specifically to source-to-destination recovery matching rather than firm-to-firm exchange or infrastructure siting.

Limitations and Future Work

This remains a proof-of-concept, and several simplifications should be named directly:

- The scenarios are constructed, not observed. All figures in Section 4 describe the demonstration set, not a real recovery system. Testing MFCMF against real material flows and real facility data is the necessary next step before any of these percentages can be treated as findings.
- Only three factors are modeled. Quality, timing, logistics, cost, and environmental impact are all left for future versions (see Section 5).
- Quantity is treated as a size label, not a real capacity comparison. As noted in Section 3.5, matching a one-time source quantity against a facility's ongoing throughput rate is an approximation; a future version should convert both to comparable units.
- The distance score depends on whichever destinations happen to be compared. As noted in Section 3.4, one unusually distant option changes everyone else's score. A fixed distance cutoff is a reasonable alternative.
- Material acceptance is Yes/No. Real facilities often have partial acceptance rules (e.g., clean cardboard only). A graded acceptance score is a natural extension.
- Equal weighting (50/50) is a transparent default, not a claim about real-world priorities. Different materials likely warrant different weightings, though this is untested here.
- A high Match Score is not a confirmed exchange. It identifies a plausible destination, not a guarantee that the exchange will actually happen.

6 CONCLUSION

Proximity tells you what's nearby. Compatibility tells you what can actually work. This paper's contribution is deliberately narrow: a transparent, extensible screen-then-rank architecture for source-to-destination circular material recovery, separating hard material eligibility from weighted destination suitability, so that a nearby but incompatible destination can never outrank one that can actually take the material.

Splitting the comparison into three methods, naive nearest, compatible nearest, and full MFCMF, showed that material screening and quantity fit each do separate, identifiable work: removing incompatible destinations changed the pick in 3 of 11 matched scenarios, and quantity fit changed the pick again in 2 of the remaining 11, even after material compatibility was already accounted for. That second effect is the more interesting one, as it demonstrates that quantity fit is not merely a downstream consequence of the material screen, but contributes distinct analytical information of its own.

The three-factor version here is a starting point, not the whole framework: material, distance, and quantity are the first three inputs into what could eventually be a much richer matching system. Validating it against real facilities and real material flows is the next step.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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