



Research article

Sustainable network design for waste mobile phone closed-loop supply chains: A multi-objective robust optimization approach under multi-source uncertainties

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Table S1. Locations of recycling centers and average daily recycling volume.

NO.	LONGITUDE (E)	LATITUDE(N)	DAILY RECYCLING VOLUME	NO.	LONGITUDE (E)	LATITUDE(N)	DAILY RECYCLING VOLUME
J1	108.34	22.84	67	J7	111.30	23.48	57
J2	108.26	22.82	46	J8	109.11	21.48	51
J3	108.30	22.77	51	J9	108.70	22.31	52
J4	109.38	24.26	41	J10	109.61	23.07	55
J5	109.43	24.27	39	J11	110.19	22.66	44
J6	110.31	25.35	48	J12	106.92	23.73	57

Table S2. Locations and capacities of testing center.

NO.	LONGITUDE (E)	LATITUDE (N)	CAPACITY
A	108.31	22.8	5200
B	108.37	21.83	4700
C	108.62	21.96	5000
D	109.43	24.34	5800
E	111.23	23.48	5100
F	110.41	23.54	4800

Table S3. Newly proposed potential center locations.

	Site selection center	PJ1	PJ2	PJ3	PJ4	PJ5	PJ6	PJ7	PJ8	PJ9	PJ10	PJ11	PJ12	PJ13
Recycling center	Longitude(E)	109.78	110.92	108.4	107.99	108.66	111.54	108.64	109.22	107.38	110.62	107.61	110.15	106.17
	Latitude(N)	25.16	23.36	21.69	21.54	21.94	24.42	24.49	23.71	22.38	25.99	21.98	23.24	23.193
Testing Center	Site selection center	G	H											
	Longitude(E)	110.1	106.93											
	Latitude(N)	25.76	23.04											

Table S4. Basic parameter values of closed-loop supply chain network for discarded mobile phones.

SYMBOL	NUMERIC AL VALUE	UNIT	SETTING CRITERIA
F_J	5	Ten thousand	Based on the construction standards for closed-loop supply networks in medium-sized cities, the parameters were set to include site leasing and basic equipment costs, in line with industry averages.
F_K	8	Ten thousand	Based on the Municipal Testing Center's annual operation report, data were obtained for costs including specialized testing equipment (such as X-ray detectors), technical maintenance, and accreditation fees.
u	500	Yuan per unit	Based on a weighted calculation involving average recycling market prices for precious metals (Au, Ag, Cu) with a $\pm 15\%$ fluctuation and resalable product revenue, a conservative valuation approach was utilized.
e	100	Yuan per unit	A Logit model was employed to quantify customer churn (5%) and brand reputation loss, which were then calibrated considering the industry competitive environment.
v	360	day	An annual operational cycle is adopted to align with the corporate financial cycle and capture seasonal demand fluctuations, such as the year-end peak in electronics upgrades.
T	30	day	Based on industry logistics turnover standards, this setup ensures efficient process linkage in collection, testing, and dismantling, effectively avoiding inventory buildup.
B_P	30	Yuan per unit	Calculated according to the Technical Specifications for Dismantling of Waste Electrical and Electronic Products, considering manual labor hours and equipment energy consumption.
B_M	200	Yuan per unit	Referencing a remanufacturing enterprise's technical report, costs cover component replacement (e.g., batteries, screens), functional testing, and quality certification.
H_J	3	Yuan per unit	Derived from warehouse rental (CNY 10/m ² /day) and system maintenance costs, values were prorated based on daily average storage volume.
B_K	50	Yuan per unit	Referencing the Guide to Cost Accounting for Electronic Product Testing, the calculation includes manual inspection time (2 hours/unit, hourly rate CNY25) and equipment depreciation costs.
B_G	10	Yuan per unit	Derived from official environmental treatment standards (e.g., heavy metal solidification, chemical neutralization), the costs are allocated according to the weight per unit of e-waste.
α	80	%	Sourced from a remanufacturing enterprise's assembly line data (78%–82%), reflecting the reparable component ratio at current technology levels, and rounded for optimization.
UC_j	2000	unit	Calculated according to daily recycling volumes (10–15 units) at 12 city collection centers and storage space limits (100 m ² , stacking density 4.5 units/m ²).
$L_{\text{新}}$	2500	Yuan per unit	Based on the weighted average market price of mainstream mid-range models (e.g., Huawei Mate, iPhone SE), this parameter covers the price distribution of 80% of in-stock products.
γ	160	%	Derived from e-commerce user review data mining (NLP sentiment analysis) and survey responses, reflecting the price elasticity of second-hand electronics.
L_0	1200	Yuan	Based on market research (1,000 samples), the median expected price for second-hand electronics is set, allowing for a $\pm 10\%$ variation.
β	80	%	Derived from historical data showing the impact of stockouts on repurchase rates (170% customer loss per unit) and the enterprise's risk tolerance.
Ω	20	%	Based on international data erasure standards (e.g., NAID, R2), a one-unit increase in perceived privacy risk results in an approximate 20% decline in expected customer satisfaction.

Table S5. Core parameter settings for uncertain conditions.

PARAMETER SETTING	SYMBOL	HISTORICAL MEAN OF PARAMETERS	PARAMETER LOWER LIMIT	PARAMETER UPPER LIMIT	PARAMETER MAXIMUM FLOATING RATIO	ROBUST PROCESSING STRATEGY	DATA SOURCE
Daily recycling volume	$\tilde{q}_j$	50	25	75	50%	Budget uncertainty set	Conversion of Recycling Ledger Data for a Certain Province from 2020 to 2022
MONTHLY MARKET DEMAND	$\tilde{Y}_{mn}$	2700	1350	4050	50%	Budget uncertainty set	Sales records of second-hand electronic products on e-commerce platforms
Recycling quality rate	$\tilde{r}$	85%	80%	90%	5.88%	Box type uncertain set	Sampling report of testing center (95% confidence interval)
Market price	$\tilde{L}_{mn}$	1500	1200	1800	20%	Polyhedral uncertain set	Historical fluctuation data of third-party price monitoring platform
Material value	$\tilde{V}_n$	300	225	375	25%	Polyhedral uncertain set	Comprehensive estimation of market price premium for recycling materials of discarded mobile phones



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