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# Repositioning in Bike Sharing Systems with Broken Bikes Considering On-site Repairs

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## 0. Study at a Glance

- **Question:** How should trucks and on-site repairers be co-optimized to keep bikes available while limiting emissions?
- **Approach:** Time-indexed MILP + Hybrid Genetic Search with Station Budget Constraint to route trucks, load/unload bikes, and allocate repair time.
- **Context:** 2-hour horizon, trucks carry usable and broken bikes, repairers fix on-site; dissatisfaction and $CO_2$ drive the objective.
- **Performance: 4–33%** better solutions than Gurobi in **6–51s**; scales to **500 stations**.
- **Key takeaway:** On-site repairers pay off when damage ratio $\geq 30\%$ and repair time $< 10$ minutes; otherwise trucks alone suffice.

## 1. Background & Motivation

**The Problem:** Bike Sharing Systems (BSS) face two critical challenges:

- **Demand-Supply Imbalance:** Stations become empty or full, causing user dissatisfaction
- **Broken Bikes:** Barcelona: 12% severe + 55% light damage; NYC: 2% need daily repairs

**Research Gap:** No existing study jointly optimizes:

1. Vehicle-based repositioning (usable & broken bikes)
2. **Labor-based on-site repairs**

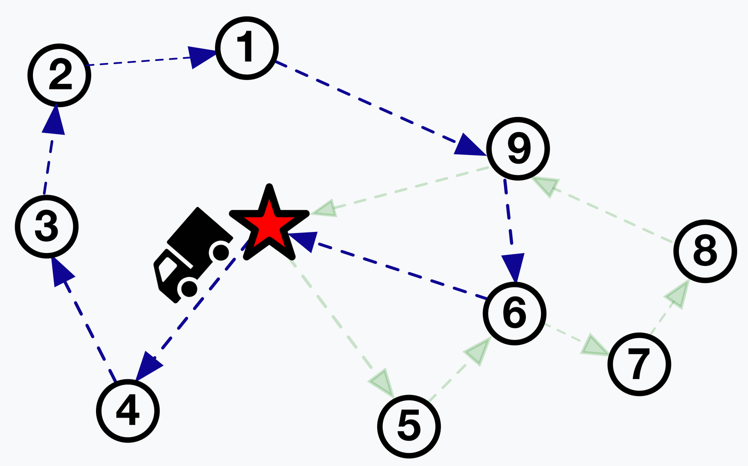

On-site repairs

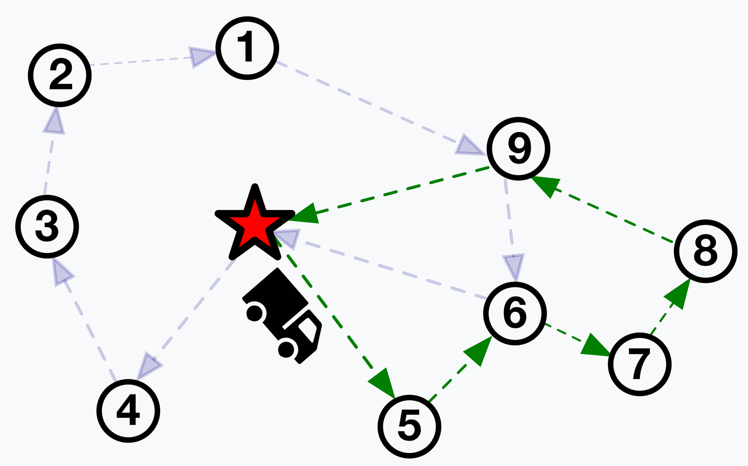

Off-site repairs

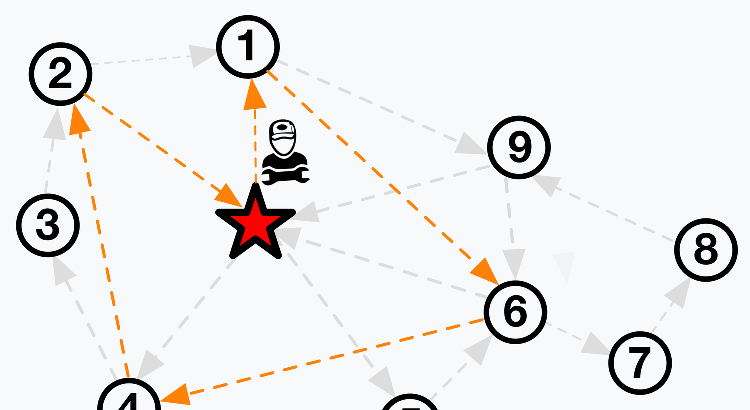
## 2. Contributions

1. **Novel Problem:** First study to integrate on-site repairs with vehicle-based repositioning operations
2. **MILP Model:** Time-indexed formulation minimizing user dissatisfaction + $CO_2$ emissions
3. **HGSDAC-SBC:** Hybrid Genetic Search algorithm with Station Budget Constraint for large-scale instances
4. **Managerial Insights:** Cost-effectiveness analysis framework for repairer deployment decisions

## 3. Problem Illustration


**Truck 1** route: 0-4-3-2-1-9-6-0


**Truck 2** route: 0-5-6–7-8-9-0



## 6. HGSDAC-SBC Algorithm

**Hybrid Genetic Search** with Adaptive Diversity Control + **Station Budget Constraint**

**Algorithm 1: HGSADC-SBC**

Initialization: Generate a population *Pop* consisting of a feasible subpopulation $Pop_f$ and an infeasible subpopulation $Pop_i$
Set *iter_no_imp* = 0 and *current_best_value* = $+\infty$
**while** *iter_no_imp* $< It_{NI}$ and *cpu_time* $< T_{max}$ **do**
Randomly select two individuals $Ind_1$ and $Ind_2$ from *Pop*
Generate the routes of offspring $C_1$ and $C_2$ using ordered crossover on the routes of $Ind_1$ and $Ind_2$, then apply the SBC heuristic on the routes to determine the (un)loading and repairing quantities for $C_1$ and $C_2$
Educate on both $C_1$ and $C_2$ by applying local search procedures to generate new routes and using the SBC heuristic to determine the (un)loading and repairing quantities
**if** $C_i$ $(i = 1, 2)$ is feasible **then**
  Add $C_i$ to the feasible subpopulation $Pop_f$
**else**
  Add $C_i$ to the infeasible subpopulation $Pop_i$ and repair $C_i$ with the probability $P_{repair}$ using local search procedures and the SBC heuristic
**end if**
**if** the individuals become feasible after repairs **then**
  The repaired individuals are added to the feasible subpopulation $Pop_f$
**else**
  The repaired individuals are discarded, and the original infeasible solution is kept in the infeasible subpopulation $Pop_i$
**end if**
**if** the size of $Pop_f$ or $Pop_i$ reaches the maximum subpopulation size **then**
  Select survivors from the corresponding subpopulation
**end if**
Set *bs* = the solution with the best fitness value from $Pop_f$ and set *bv* = the fitness value of *bs*
**if** $bv \geq$ *current_best_value* **then**
  Set *iter_no_imp* = *iter_no_imp* + 1
**Else**
  Set *current_best_value* = *bv*, *current_best_sol* = *bs*, and *iter_no_imp* = 0
**end if**
**if** *iter_no_imp* $\geq It_{div}$ **then**
  Diversify the population consisting of $Pop_f$ and $Pop_i$ and adjust the penalty parameter
**end if**
**end while**
**return** *current_best_sol*, *current_best_value*

## 7. Station Budget Concept (SBC)

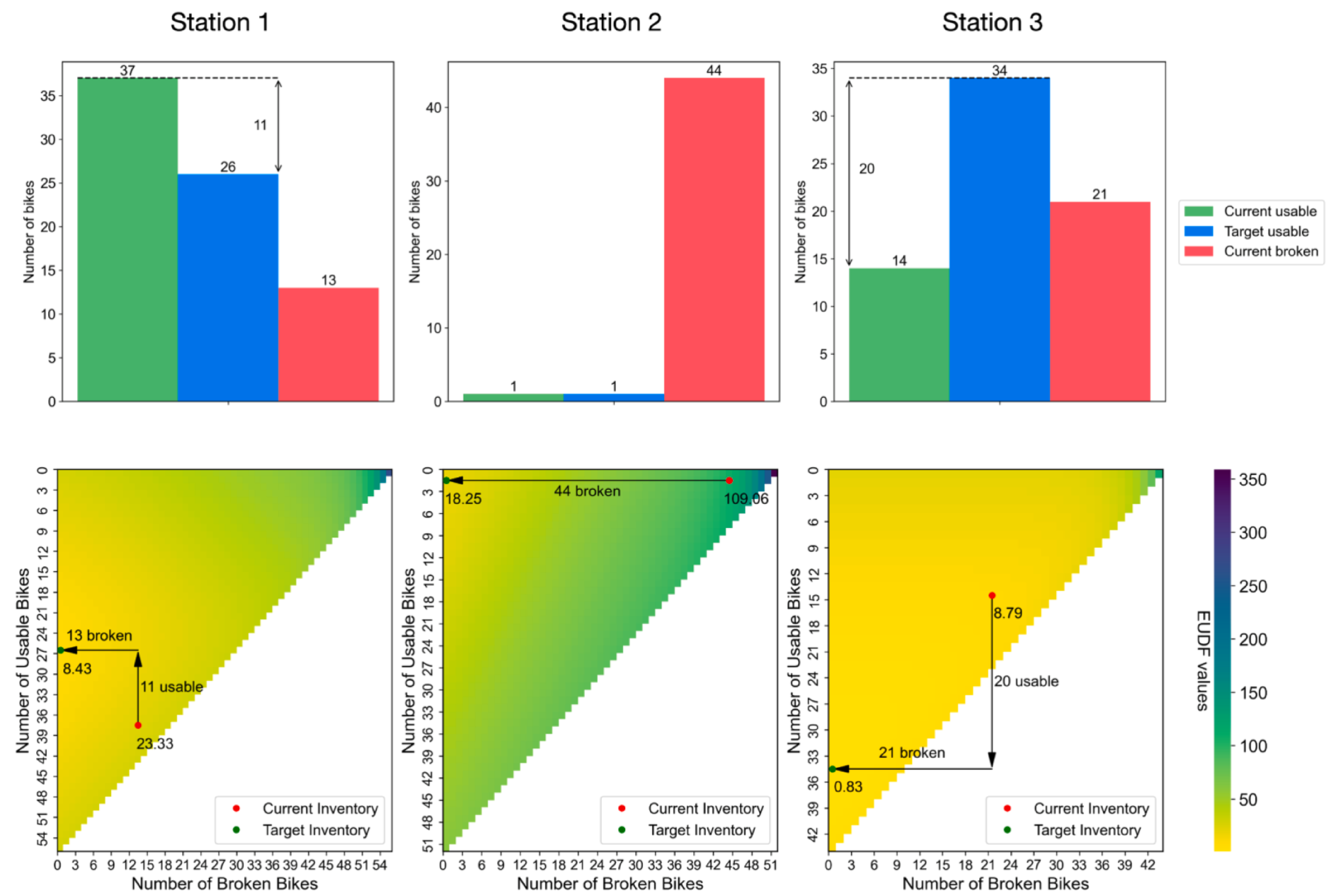
**Key Innovation:** Prevents over-allocation of service time to early stations

**Benefit-Cost Ratio Function (BCRF):**

$$BCRF_s^t(p, b) = \frac{F_s(p, b) - F_s(q, 0)}{t^{load} \cdot (|q - p| + b)}$$

- Quantifies dissatisfaction reduction per unit service time
- Higher BCRF stations receive larger time budgets
- Unused time redistributed dynamically to later stations

## 8. BCRF Illustration




$$BCRF_1^1 = \frac{23.33 - 8.43}{(11 + 13) \times 60} = 0.0103 \quad BCRF_2^1 = \frac{109.06 - 18.25}{44 \times 60} = 0.0344 \quad BCRF_3^1 = \frac{8.79 - 0.83}{(20 + 21) \times 60} = 0.0032$$

**Fig. 4.1:** BCRF calculation for 3 stations. Top: inventory status; Bottom: EUDF heatmaps.

## 9. Computational Results

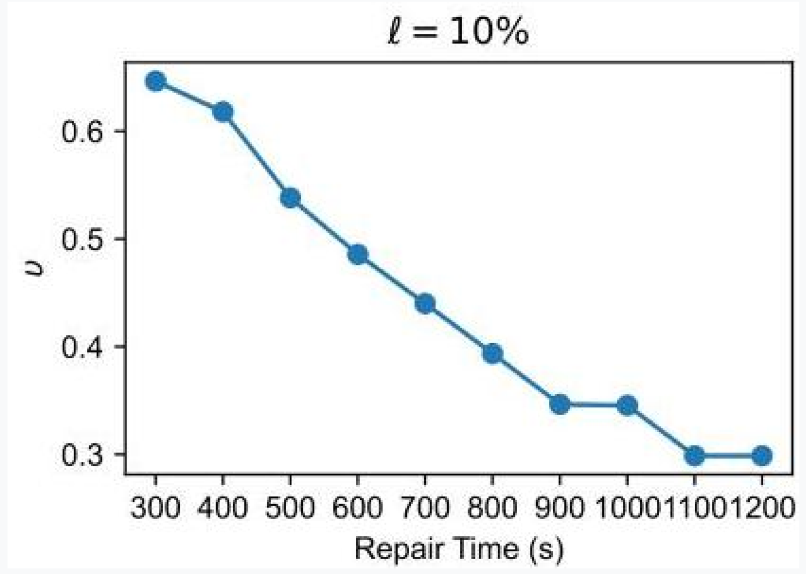
**Comparison vs Gurobi** (T=2h, $\tau$=600s, 20 runs)

## 10. Cost-Effectiveness of Repairers

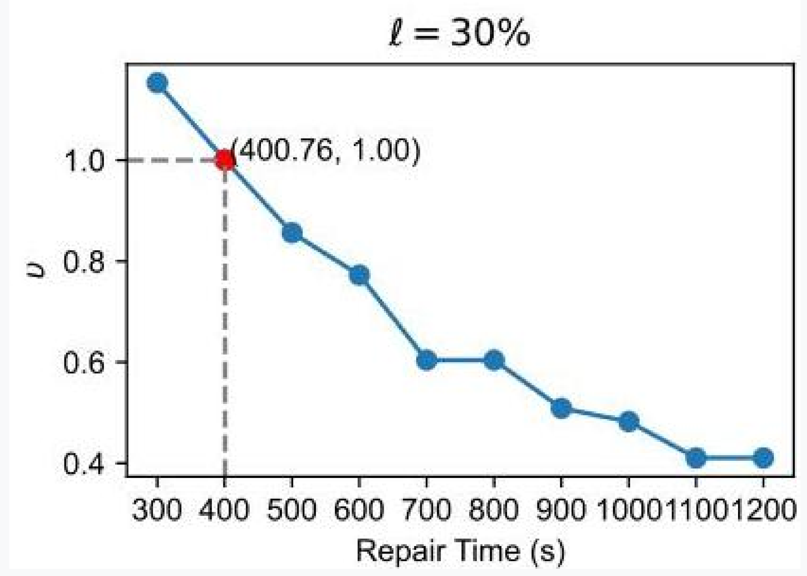
**Indicator** $\nu$: Ratio of dissatisfaction reduction to repairer wage

$$\nu = \frac{c^p \sum_{i \in S}(\widehat{F}_i - \widehat{F}_i')}{\varpi \cdot T/3600}$$

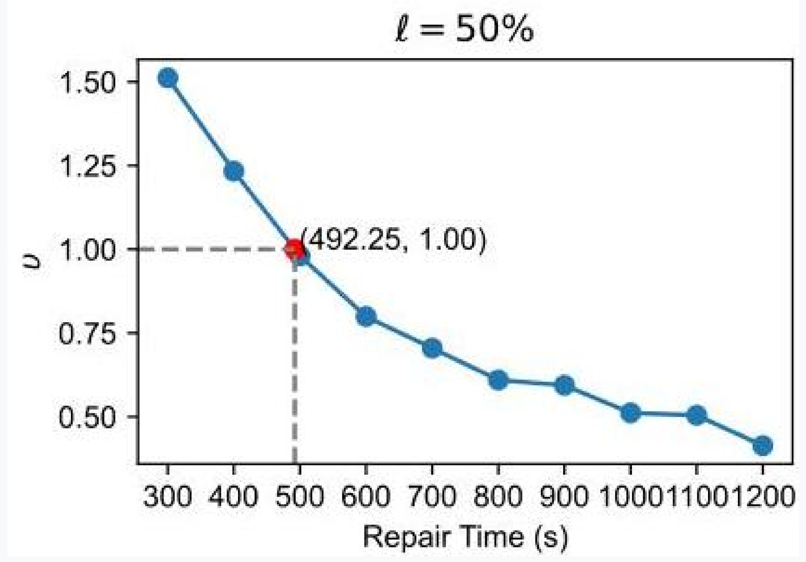
$\nu > 1$: Cost-effective $\quad \nu < 1$: Not cost-effective



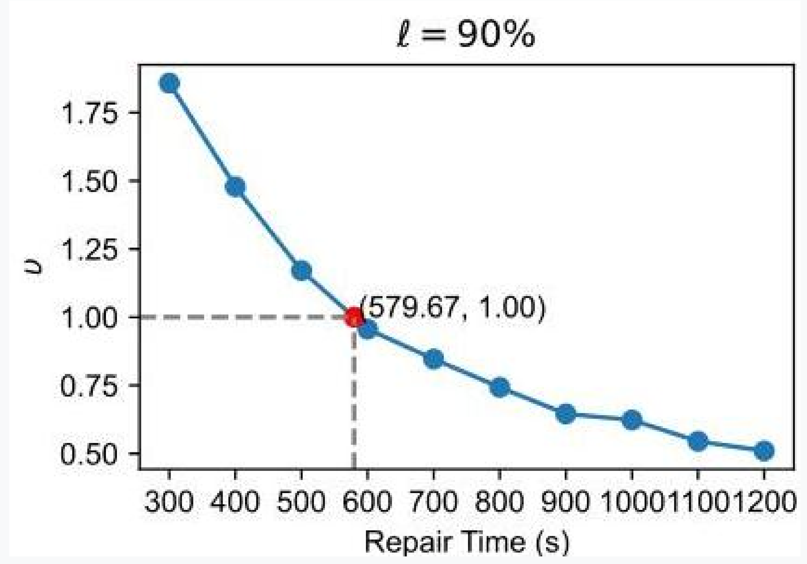
$\ell = 10\%$: Never effective



$\ell = 30\%$: Threshold 401s



$\ell = 50\%$: Threshold 492s



$\ell = 90\%$: Threshold 580s

Higher broken ratio ($\ell$) $\rightarrow$ repairers effective at longer repair times

## 11. Key Managerial Insights

- **Critical Threshold:** Repair time $> 645$s $\Rightarrow$ **never** cost-effective
- **Low damage** ($\ell < 20\%$)**:** Trucks alone sufficient; repairers not justified
- **High damage** ($\ell \geq 30\%$)**:** On-site repairers become economically justified
- **Preventive maintenance** crucial to keep repair times below threshold

## 12. Conclusions

1. HGSDAC-SBC is **scalable** for real-world BSS (up to 500 stations)
2. Station Budget Constraint effectively balances time allocation across route
3. Dynamic repairer deployment should adapt to daily damage levels

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## References

Hu, R., Szeto, W.Y., & Ho, S.C. (2025). Repositioning in bike sharing systems with broken bikes considering on-site repairs. *Transportation Research Part E*, 104155.

**Scan for full paper:**

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