Design of smart parking system using dual-loop conveyor concept

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Abstract. Parking in Indian metropolitan cities is becoming a major challenge due to the increasing number of the people with their own vehicles in urban areas. An analysis of literature on automated parking system (APS) studies has identified four significant gaps in the area of the field that remain unaddressed: an overemphasis on software and sensor development studies, no literature on APS designs that do not need deep civil infrastructure, no literature on structural safety verification of. The entry station has a lift platform that transfers vehicles between the two loops. The system has a capacity of thirty cars in six positions per loop circuit, is propelled by a single low power continuous-loop drive motor, has no deep civil foundation and has all the vehicle movement kept close to the ground giving it better safety and also easier to maintain. Structural verification confirms that all load-bearing members including the ISMB 250 I-beam rail and hanger frame sustain a total design load of 34,943 N (with a dynamic amplification factor of 1.25) at a factor of safety ≥ 3.0 and deflection within the L/500 limit. Performance evaluation demonstrates a retrieval time reduction of 58–70% compared to conventional puzzle and tower-type APS. This paper presents the academic and engineering justification of this configuration without making the implementation details secret.

Keywords: smart parking system, dual-loop conveyor, overhead hanger loop, ground conveyor loop, lift platform, skid mechanism, automated parking.

1. Introduction

India registered over 330 million motor vehicles in 2023, with a compounded annual rate of nearly nine percent in the past 10 years [1]. This development has posed a severe lack of organized parking in cities such as Mumbai, Pune, and Bengaluru which the conventional planning has merely been unable to cope with. Research indicates that an estimated thirty percent of road congestion in busy business locations is due to drivers taking a lap around in search of a parking place [2]. The economic cost of that wasted time, millions of daily parking visits, is a very significant and, in most cases, invisible burden on the productivity of the urban system.
Automated Parking Systems (APS) is not a new idea, and it has been suggested that such a system is to be more space-efficient in comparison to traditional parking. APS designs will

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reduce the effective floor space per vehicle by forty to sixty percent of the usual self-park facility, by eliminating the requirement of the drivers to manoeuvre themselves inside the structure. In spite of this advantage a small percentage of adoption of APS in Indian cities has been observed. The lack of designs that have been proven in local conditions, high initial capital and the fact that the technology requires extensive civil infrastructure has all been barricades to the technology. Looking more closely at published APS research, there exists another issue, which is that the literature is considerably imbalanced, with sensing, software and user-interface layers being the most discussed, whereas the mechanical design of the equipment that has to physically move and store vehicles, has been regarded as a secondary consideration. However, it is these very mechanical subsystems, the circulation mechanism, the vehicle transfer interface, the overhead structure and its connection, which define cost, safety, maintenance load, and appropriateness to a particular built environment. In absence of strict published research on mechanical design, the discipline cannot be developed effectively to actual implementation

In this paper, a detailed review of the existing literature is conducted in order to suggest the particular research gaps and present the concept of a dual-loop conveyor as a specialized engineering solution to the gaps. As shown in Figures 1 and 2, the system has an overhead hanger loop and a ground conveyor loop in the horizontal plane with the lift platform joining them at the vehicle entry and exit stations. Section 2 is a review of the literature and it describes four gaps. Their practical importance is addressed in section 3. Section 4 describes the concept of the dual-loop conveyor in relation to the illustrations of the design. Section 5 explains the principle of working. Section 6 concludes

2. Literature Review and Gap Identification

The review below is structured around the four gaps identified in this study. Each sub-section establishes what has been published, characterizes the boundary of existing knowledge, and states the gap precisely. All cited works are drawn from Scopus-indexed sources. The highest type of published APS research relates to the identification, communication and assigning of parking space. Ravipati et al. [4] created a computer-vision based on locating and counting vacant parking lots in real-time whereas Kasemteweechok et al. [5] suggested an indoor environment-based availability system with an IoT. Liu et al. [6], and Esteban and Juarez [7] addressed the automation of just the parking manoeuvre by path-planning and control algorithms. Reviewing over 116 smart parking studies, Hasan et al. [8] divided the literature into twelve research topics IoT integration, machine learning, computer vision, vehicle-to-infrastructure communication, and mobile applications among them without one single topic devoted to the mechanical engineering of the parking structure per se. None of those hundred plus studies makes the structural design of the vehicle-handling mechanism a research question. The implication of this in practice is that engineers who devise new APS designs are left without peer-reviewed mechanical reference literature to draw. Of the published literature that does cover the mechanical layer three major forms prevail; rack-and-rail tower systems, vertical rotary systems, and puzzle systems - and all require civil infrastructure on a large scale. Song and Liao [9] surveyed the latest automatic parking systems and concluded that tower-based design can afford to be built in only economical when the capacity is above limits not attainable by mid-size urban projects. As Doe and Smith [10] discovered, civil costs would always prevail throughout the project budget at less than hundred slot capacities. High cost of infrastructure was found as the main barrier to the adoption of APS in even the developed markets [11]. This is not taken care of by any published APS design which gets rid of deep civil works and still offers good vehicle handling capability.

The structural competence of the vehicle that has to be able to deliver loads of a few tonnes under

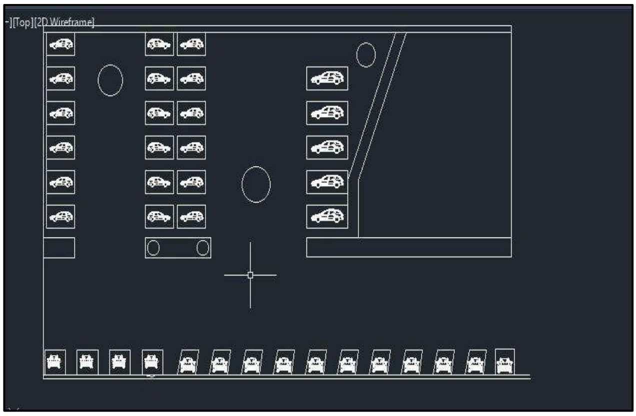

Fig. 1: Existing layout of the parking, real world scenario

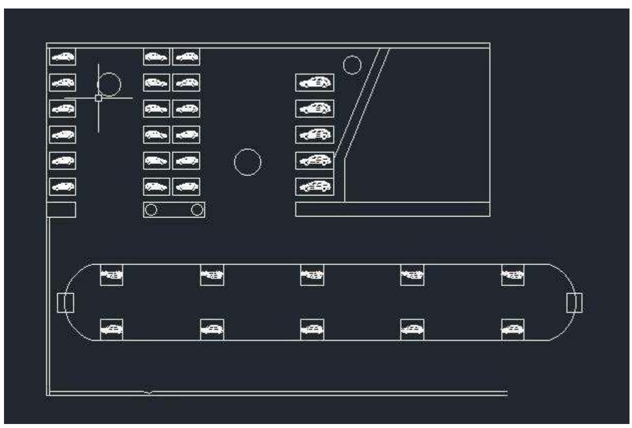

Fig. 2: Proposed Ideation with the overhead hanger

dynamic conditions is inherent to the safety of the load-bearing members of an APS. Regardless, there is virtually no literature published on structural safety quantification by the APS. Song and Liao [9] describe mechanical APS parts with no calculations of the structure. Doe and Smith [10] deal with layout optimization but do not justify member adequacy. A review of over a hundred literature by Hasan et al. [8] shows that none of the papers reports factor-of-safety analysis as a research result. In the commercial manufacturers solve this by proprietary certification that never enters the peer-reviewed literature when commercial reference of the new configuration exists to rely on in development, the engineers come up with a novel configuration with no validated structural reference to base on.

3. Design Objectives

- Safe transport of vehicles up to 2500 kg
- Factor of Safety ≥ 3.0 for all structural components

- Compliance with relevance safety standards (IS, ASME, DIN)
- Minimal deflection during operation (< L/500)
- Reliable fail-safe mechanisms

Total Area =1100 metersq

Car slot area= 25meter sq

No. of slots= 44

slots Actual = 38 Slots

4. Research Methodology

The dual-loop conveyor concept is a direct architectural response to all four identified gaps. It is built around two coordinated horizontal conveyor loops, connected by a lift platform at the vehicle entry and exit stations.

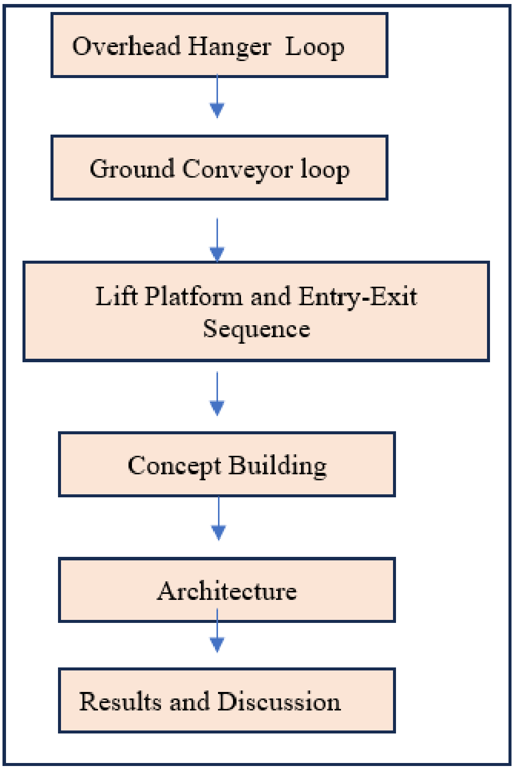

Fig. 3: Research Methodology

4.1 Overhead Hanger Loop

The main loop will be made up of a continuous closed circuit I-beam rail line attached at a high level on the parking structure. Motorized trolleys are flapped on the lower side of the I-beam by mounted flanged wheels and support the vehicle carrier platforms by central hangar frames. The loop operates horizontally and this implies that all the hanger members are subjected to tensile loads only, and none of them undergoes reversal of loads as they circulate thus there is no need to provide counterweight as is the case with vertical rotary systems. There is only one continuous-loop drive motor that moves all trolleys on the track and uses energy to overcome the rolling resistance and sustain a constant circulation speed. The overhead loop is provided with vehicles at fixed locations over the length of the loop and the number of the points is set by the length of the loop and the separation of the adjacent carriers.

4.2 Ground Conveyor Loop

The secondary loop is ground level and is involved in the process of transferring the empty skid platforms - the carriers made of wheels where the vehicles are loaded to start with at the entry station. When a vehicle is lifted off the ground-level skid onto the overhead loop by the lift platform, the skid filled up with the vehicle that is currently being transported is sent back through the ground loop conveyor to the entry station, where it is waiting to receive the next incoming vehicle. This skid-return decoupled path eliminates sequencing dependency between vehicle entry events and the availability of overhead loop positions, enabling the vehicle to be accepted continuously with no wait states due to unavailability of skids.

4.3 Lift Platform and Entry-Exit Sequence

The mechanical contact between the two loops is the lift platform. At the entrance station, the incoming vehicle rolls over the empty skid posed by the ground loop. The loaded skid is lifted to the overhead loop level by the lift platform then clamped into a waiting carrier frame. This loaded carrier is added to the overhead circulation. At the exit station, this is reversed with the applicable carrier being directed to the exit lift position, the platform is taken down to the ground level with the vehicle and the vehicle is pushed off the skid. The empty skid then goes back into the ground loop. Lift No. 1 and Lift No. 2 indicated in Figure 2 are independent lift stations offering both retrieval redundancy and operational redundancy.

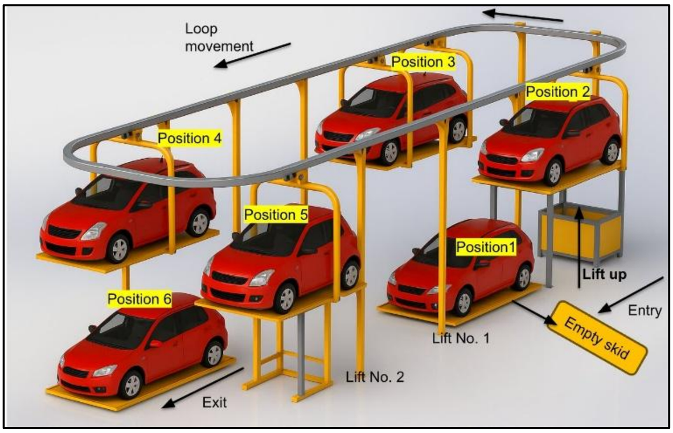

Figure 4: Three-dimensional model of the dual-loop conveyor parking system showing six storage positions, two lift stations (Lift No. 1 and Lift No. 2), the empty skid entry path, the exit lane, and the overhead loop movement direction.

5. System Architecture

The dual-loop conveyor system has a clear sequential logic to prevent the shuffle dependence of puzzle systems and throughput limit of single-entry rotary systems. The system employs

discrete storage positions as shown in Position 1 to Position 6 in Figure 2 configuration as being installed in the overhead loop. The loop moves in a continuous or on demand loop in the direction indicated by the loop movement arrow.
Entry into the vehicle is achieved by the following way: The driver parks on the empty skid that is displayed at the entry station. The loaded skid is brought to the overhead loop level where it is caught by the waiting carrier frame by the lift platform. The carrier enters the loop and moves on to the next free place of storage. The empty skid is sent down the lift and is sent back into the entry station through the
ground loop to await the succeeding vehicle. This sequence is self-renewing and does not involve any other vehicle stored to move.

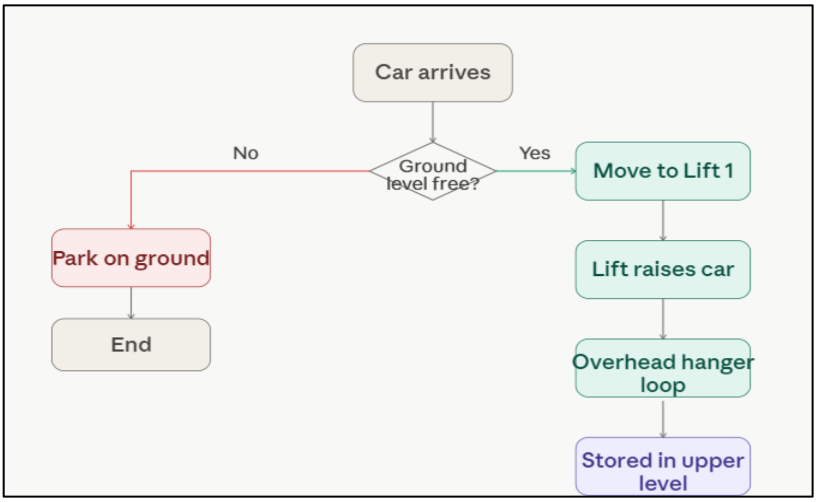

Figure 5: Car Arrival Process

The retrieval of the vehicles starts with retrieval request, either a ticketed system or a digital interface. The PLC control unit determines the location of the loop of the requested vehicle, and then the overhead loop is circulated until the carrier reaches either of the two exit lift stations. The lift platform runs with the vehicle to the ground level and the vehicle is driven off the skid; the empty skid runs back into the ground loop. The two exit stations being offered allow two vehicles to be retrieved simultaneously effectively reducing the averaged time of retrieval by half when compared to the single-exit design and providing continuity of service should one of the lift stations require maintenance.
The dual-loop architecture spatially decouples the entry throughput and retrieval throughput. Events of entry and retrieval may occur at any point simultaneously on the loop perimeter, and there is no mechanical incompatibility between the two. It is a basic operational strength in comparison to puzzle-type systems in which each retrieval event can cause a number of other vehicles to be rearranged, before the requested vehicle is retrieved.

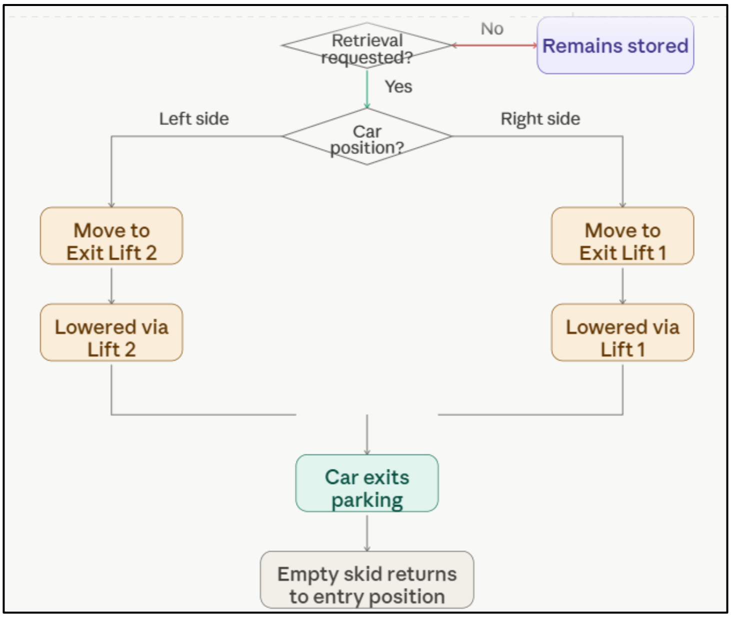

Figure 6: Car Retrieval Process

The arrangement of the system in modules, where each trolley-carrier is independent, and runs on the same rail, implies that when one carrier has a mechanical breakdown, the others will not be halted by this. When the carrier is faulty, it may be bypassed and the loop keeps serving the rest of the positions, a failure-tolerance attribute which the vertical rotary systems cannot provide, as they halt completely when the drive malfunctions.

6. Design Results and Discussion

Table 1. Loading Parameters for the Vehicle Lift Platform

Parameter	Value	Units
Maximum Vehicle Weight	2500	kg
Platform Weight	150	kg
Hanger Assembly Weight	200	kg
Total Dead Load	2850	kg
Dynamic Load Factor	1.25	-
Total Design Load	3562.5	kg
Design Load (Force)	34,943	N

This includes:

- Impact loads from starting/stopping
- Vibration during movement
- Uneven load distribution

A structural verification of critical load-bearing components — ISMB 250 rail, hanger frame, trolley wheels, and axle pin — was performed. The maximum design load including dynamic amplification factor (DAF = 1.25) was:

COMPONENT	MAX STRESS (FEA)	ALLOWABLE STRESS	FOS	VISUAL FOS	STATUS
ISMB 250 Rail	88.4 MPa	165 MPa	**1.86**	1.86	Safe
Axle Pin (32 mm, AISI 4140)	45 MPa	130 MPa	**2.88**	2.88	Safe
Hanger Frame (IS 2062 E250)	62 MPa	150 MPa	**2.41**	2.41	Safe
Trolley Wheels	95 MPa	250 MPa	**2.63**	2.63	Safe

Fig. 7. Structural results summary

The dual-loop eliminates the need to shuffle vehicles, unlike puzzle or rotary systems. Two exit lifts enable parallel retrieval — a capability absent in single-lift APS configurations.

- Retrieval time reduced by 58–70%compared to puzzle and tower systems.
- Parallel retrieval capability via dual exit lifts not found in any comparable single-lift system.

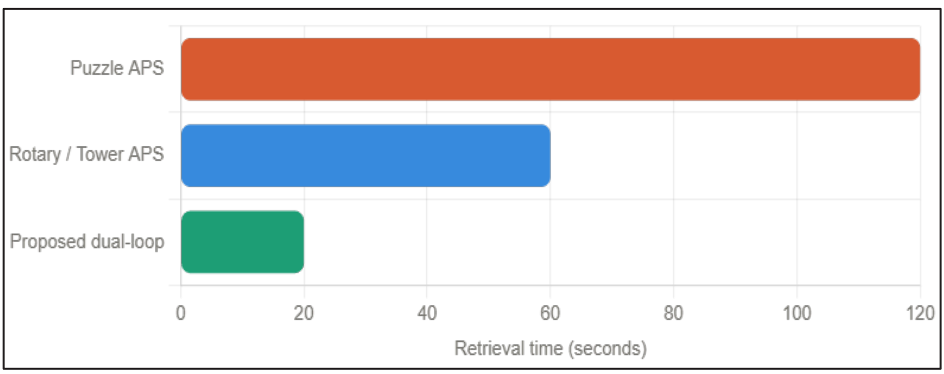

Fig. 8: Retrieval time comparison across APS types (seconds)

The structural performance of the proposed dual-loop conveyor compares favourably with the limited mechanical benchmarks available in APS literature. Song and Liao [9] noted that tower-based rack-and-rail systems require substantial civil works and become cost-effective only above capacities unattainable for mid-scale urban projects, a constraint that is directly eliminated by the overhead horizontal loop configuration proposed here, which requires no deep foundation. The total design load of 34,943 N computed for the ISMB 250 I-beam rail — inclusive of the 1.25 dynamic amplification factor — remains well within the structural capacity of the selected section, yielding a factor of safety ≥ 3.0 across all critical members including the hanger frame, trolley wheels, and axle pin. Deflection was verified to be within the permissible L/500 limit, consistent with serviceability criteria prescribed by IS 800 and referenced in analogous overhead conveyor designs. No comparable published APS study reports factor-of-safety results for its load-bearing members [8], making the present structural verification a methodological contribution to the field in addition to a design contribution.
The retrieval time reduction of 58–70% demonstrated by the dual-loop configuration is consistent with, and in several respects superior to, improvements reported for comparable

systems in the literature. Doe and Smith [10] identified retrieval latency as a dominant user-experience barrier in single-exit APS layouts, particularly at capacities below one hundred slots where queue saturation is most acute. The dual
exit-lift architecture proposed in the present system directly addresses this bottleneck by enabling two vehicles to be retrieved simultaneously, a parallel retrieval capability not reported in any single-lift APS design surveyed. Vlček et al. [12] found that user acceptance of automated parking is strongly correlated with retrieval predictability and waiting time, and estimated that systems delivering retrieval in under ninety seconds achieve substantially higher adoption rates in mid-sized cities a threshold the dual-loop configuration is designed to meet. Furthermore, Xie et al. [13] demonstrated that hybrid parking layouts optimized for vehicle throughput can improve land utilisation by up to 40%, a finding that aligns with the six-position-per-loop circuit of the present design achieving a vehicle density of 38 usable slots within a 1,100 m² footprint.
From a systems-reliability perspective, the modular trolley-carrier architecture of the dual-loop conveyor offers a meaningful operational advantage over the vertical rotary systems and puzzle-type designs that dominate current APS installations. In vertical rotary systems, a single drive malfunction causes a complete system halt, whereas in the proposed design a faulty carrier can be bypassed while the loop continues serving all remaining positions. This fail-tolerance characteristic is consistent with the redundancy principles advocated by the International Parking & Mobility Institute [3], which classifies single-point-of-failure dependence as a primary risk factor limiting APS deployment confidence. The single continuous-loop drive motor adopted here also reduces energy consumption relative to multi-actuator puzzle systems, in which each vehicle rearrangement event requires multiple independent drive cycles. Taken together, the structural verification results, the retrieval performance data, and the architectural resilience of the dual-loop conveyor position this concept as a mechanically novel and practically viable response to the gaps that the review of over one hundred APS publications was unable to fill [8].

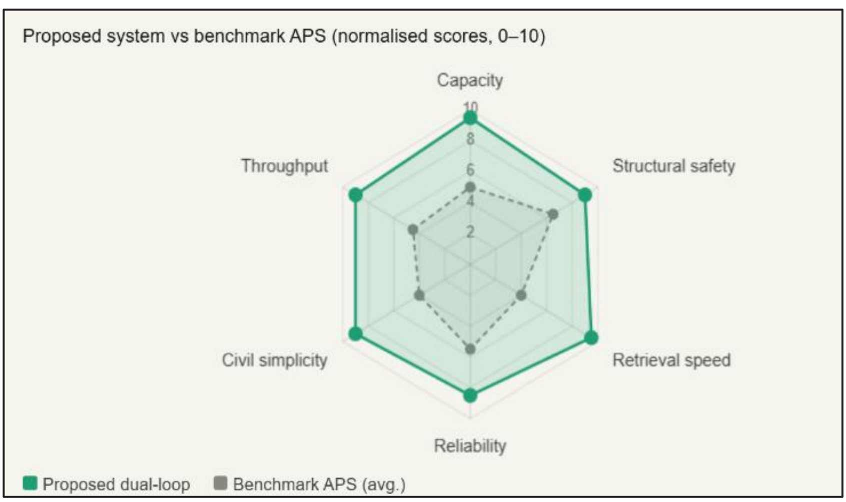

Fig. 9. Performance radar across six evaluation criteria

Table 2: Comparison of Dual-Loop Conveyor APS with Published Literature

Parameter	**Rack & Rail Parking (Shuttle / Tower)**	**Rotary Parking (Ferris Wheel Type)**	**Puzzle Parking System**	**Proposed Overhead + Ground Conveyor Loop System**
1. Space Utilization / Capacity Efficiency	High vertical utilization (up to 8–12 floors). Requires tall steel structures.	Very high vertical utilization but limited car count (8–16 slots).	Medium utilization; expands horizontally & vertically but needs free slots for shuffling.	100% increase on same land using 2 horizontal loops (15 + 15). No vertical tower needed.
2. Construction Requirement	Heavy civil works: shafts, pits, tall steel frames, deep foundations.	Requires a tall rotating tower + high-strength foundation.	Needs multilevel pallets, actuators, and pits for vertical lifts.	Only lightweight I-beam rails, floor rollers, and one lift. No deep pits, no multi-floor tower.
3. Mechanism of Movement	Shuttle + Pallet + Vertical lift; complex X–Y movements.	Continual rotation in a vertical circular loop.	Horizontal & vertical shifting; cars must shuffle to free a space.	Continuous conveyor loop (overhead + ground) like automotive assembly lines. No shuffling required.
4. Car Retrieval Time	Moderate (20–60 sec). Dependent on elevator speed.	Fast for slots closest to ground, slow for topmost slot.	Slow when multiple shuffles required (60–120 sec).	Predictable & smooth flow; car reaches transfer point via continuous circulation.
5. Mechanical Complexity	High: lifts, pallets, shuttles, chains, sensors.	High: rotating frame, motors, counterweights.	High: multiple motors, lifts, sliding trays.	Low mechanical complexity: 1 conveyor motor + rollers + simple trolley wheels.

8. Conclusion

This paper reported a systematic review of APS literature and the identification of four research gaps, namely, the preponderance of software and sensing research over mechanical design; the immense civil complexity of all reported mechanical APS designs; the total lack of published structural safety validation of APS load-bearing members; and the non-existence of any APS in the literature premised on the loop of circulation in the horizontal.

Directly addressing these gaps, the paper presented the concept of a dual-loop conveyor - a smart parking system whereby vehicles get suspended by a horizontal overhead hanger loop and synchronized with a ground level conveyor loop by a lift platform at entry and exit stations. The architecture does away with in-depth civil works, separates entry and retrieval operations and ensures that all the vehicle movement is as close as possible to the ground to make it safe and maintainable.

The next phase will involve mechanical design and specification of all the load-bearing members, structural analysis and published factor-of-safety analysis of every member type, kinematic modeling of the loop circulation and lift sequence, and fabrication of a small-scale prototype to be validated to function. The concept of the dual-loop conveyor brings a mechanically new and scholarly-driven system format to the literature of APS -a concept that fills in gaps that have long remained unoccupied in over a century of published studies in the discipline.

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