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FACULTY OF CIVIL TECHNOLOGY AND GEOSCIENCES

USE OF UNDERGROUND SPACE
(CT 3300)

PROJECT REPORT

AUTOMATED UNDERGROUND CAR PARKING AREAS

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PREFACE

With the industrial development and growth of transportation infrastructure, the problem for parking of vehicles is getting more and more importance, especially in big cities, where there is shortage of space and problems due to traffic congestion. This report gives the overview of the underground parking systems. With the further innovation of technologies and improvements in design structures, now days more modernized underground parking structures are being developed. These are commonly known as automated and intelligent parking garages. This report focuses on different aspects of conventional and automated underground parking facilities. In the end, we have try to conclude our work and presented few recommendations, so that the increasing demands for parking places must be met in time.

We hope that this report will help the reader to develop basic knowledge about the underground parking systems, and enhances his/her technical concepts regarding future of underground parking systems.

STUDENTS

SUMMARY

The maturity of underground car p arking garages / stru ctures is g etting important to achieve a comfortable urban transportation system, and effective use of underground space is particularly necessary in congested cities. However, maintaining an appropriate atmosphere in the und erground parking areas r equires more equipment and con sumes more energy than t ypical above ground parkin g areas. In this report, we have tried to cover different aspects of the conventional and automated underground parking structures. We have basically focus ed on the a utomated underground parking gar ages that are a facility that makes best use of available space below ground, with less environmental impact it reduces opportunities for theft and burglary.

The report is aimed to research underground parking garages. In this study, we will focus on comparison between conventional underground parkin gs garages and automated underground parking garages. The detail of comparisons is discu ssed in Chapter No.3, however the highlighted points of comparison include;

- Basic Requirements
- Car Park Types
- Capacity & Size
- Time
- Costs
- Environmental Aspects
- Risks
- Legal Aspects
- Services
- Enhancements

The purpose of this st udy is to give reader so me basic inf ormation about conventional and automated underground parkin gs. After co mparing the two types of underground parkings, then we ha ve suggested some of the improvements for t he underground parking garages.

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1.0 Introduction

As the number of automobiles around the world increases exponentially, finding places to park them becomes increasingly difficult. Due to the fact that the most parking spaces are necessary in urban areas, this poses a challenge to make parking garages as efficient as possible. Not only location of the garage is important, but also its capacity, the time it costs tenants to use them, and environmental aspects as well. In order to meet the rising demand for parking areas it is necessary to look for innovative and more efficient ways of using space in urban areas.

This report covers two types of parking systems in use today and evaluates them on crucial aspects. The parking systems in question are the conventional parking garage that we are used to, and the relatively new automated parking garages. The focus here will be mainly on underground parking facilities, where risks, energy consumption, and costs differ greatly with surface parking facilities. The construction and management of parking garages is heavily dependent upon:

- Economic and financial feasibility;
- Characteristics of the site and the surrounding neighborhood;
- Parking demand, supply, requirements and attitudes; and
- Market issues.[1]

The development of underground car parking areas is important to achieving a prosperous urban environment, and effective use of underground space is particularly necessary in congested cities. However, maintaining a proper environment in underground parking areas requires more equipment and consumes more energy than typical above ground parking areas. In many districts where urban activity is high, the capacity of the dedicated parking areas is already far below the minimum necessary capacity and parking demands continue to increase.[2] The challenge to engineers here is constructing to the need for more intense land-use, and for more efficient ways of parking vehicles.

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[1] *K. Matsushita and Others. 1993.* ***An Environmental Study of Underground Parking Lot Developments in Japan.*** *Tunneling and Underground Space Technology, Vol.8, No.1, pp65-73.*

[2] *Press Release Source.* ***AutoMotion Parking Systems****. AutoMotion Introduces First Fully Automated Parking Garage In N.Y.C. < http://www.automotionparking.com/>*

2.0 Conventional Underground Parking Garages

2.1 Introduction

A parking area (known as a car park in countries or car lot) is a cleared area that is more or less level and is intended for parking vehicles. In most countries where cars are the dominant mode of transportation, parking lots are a feature of every city and suburban area. Shopping malls, sports stadiums, mega churches and similar venues often feature parking lots of immense area. There are various types of parking facilities:

- On street parking consists of parking lanes provided within public road rights of way;
- Off street parking is parking facilities on their own land, not on road rights of way;
- Surface parking refers to parking lots directly on land;
- Structured parking is parking facilities in or under multistory buildings.

Parking lots are usually paved with asphalt or concrete, although off-street parking may also have gravel or sand as a sub-surface. A few of the newer lots are surfaced with permeable paving materials. While parking lots have traditionally been an overlooked element of development projects by governmental oversight, the recent trend has been to provide regulations for the configuration and spacing of parking lots, their landscaping, and drainage and pollution abatement issues.[1]

Parking lots can be small, with just parking spaces for a few vehicles, very large with spaces for thousands of vehicles, or any size in between. Small parking lots are usually near buildings for small businesses or a few apartments, although many other locations are possible. Larger parking lots can be for larger businesses or those with many customers, institutions such as hospitals, museums, tourist attractions, and larger apartment buildings.[2]

[1] ***Parking Lots***. *<http://en.wikipedia.org/wiki/Parking_lot>*

[2] ***Parking Facilities***. *<http://www.wbdg.org/design/parking.php >*

2.2 Basic Requirements of Conventional Underground Parking Garages

Few of the basic requirements of conventional underground parking garages are highlighted below;[3]

Column Centers: In a conventional car park there should be no columns to impede access to parking spaces. In basement car parks this is difficult but not impossible to achieve. Where the standard 7.2m grid is used, designers need to recognize that the notional advantage of allowing for three spaces, each of 2.4m width between column centers, is lost once real columns (400 x 400) are inserted - the space is reduced to 6.8m. Designers should allow for 7.2m (or other multiples of 2.4m) clear between column edges so that full width spaces are available to patrons.

Head Clearance: Flat ceilings are preferable in all car parks. Structural beams should not be located in the vicinity of parking spaces, and if this cannot be avoided then allowance must be made not only for the height of car roofs but also for the height of hatch back doors which swing up.

Intrusions: Where ramps intersect with floors at parking spaces, the design needs to ensure that tall pedestrians don't risk cracking their skulls, or that tall vehicles don't have their roofs removed. Plinths that catch opening car doors or walls that protrude into circulation pathways are design challenges and should be eliminated.

Number of Lanes: Most car parks of up to 500 spaces require only one entry lane - possibly with twin ticket dispensers - as they usually face a pinch point which effectively means that only one line of cars can actually navigate 20 meters after the entry barrier. A minimum of 2 exit lanes are required at all automatic car parks, to allow for the patron who loses their ticket and blocks a lane while staff deal with them, or due to some other problems like car ignition problems.[4]

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[3] *Asian Development Bank. 2003.* ***Policy Guidelines for Reducing Vehicle Emissions in Asia****. Transport Planning and Traffic Management for Better Air Quality. Manila. Philippines.*

[4] ***Car Park Design.*** *<http://www.parkrite.ie/design1.htm>*

Lifts: Lifts (8~13 person) are essential if any reasonable comfort is to be provided, and these need to be in pairs. Smaller lifts do not meet the needs of people with shopping trolleys or baby buggies or large packages.

Lighting Standards: Old recommendations on internal lighting standards e.g. of 50lux, have long ago been discarded by the industry and replaced by minimum standards of 100lux and 250 to 350lux at entrance/exits. White fluorescent bulbs provide the best quality of light. Tungsten lamps generally give yellow tints and leave "cave" effects unless used in high densities. Lighting in stairwells and lobbies need to be to a very high specification to minimize perceptions of personal isolation.

Lines of Sight: Personal security is greatly enhanced in car parks where lighting levels are high and clear lines of sight are designed into a facility e.g. at access points to lift lobbies, stair lobbies, at corners on pedestrian routes. In addition all doors, including lift doors, should have large glass panels, all walls should have large glass windows so patrons can check whether it is safe to pass through or not. Structural walls can have 'openings' cut into them, to increase natural light penetration and improve sight lines.

Main Lobbies: The main lobbies of public car parks need to be sufficiently large and well laid out to accommodate the very large peak flows of patrons from lifts, stairs and ground floor areas, who are going to /from their cars and stopping to pay for their parking at pay stations or customer service desks. In addition, the area should allow plenty of room for vending machines, public phones, seating areas, litter bins and appropriate signage.

Office/Kiosk: Conventional car parks require proper accommodation for staff including canteen, toilets and lockers in addition to the CCTV, PC & printer, intercoms, safe, supply stores, customer service window, phone/fax, wet/dry cleaning room, ticket storage etc. A minimum of 30 square meters is required.

Ramp Widths: Ramps in car parks need to be a minimum of 3 meters, to avoid collisions between ramp walls and vehicles. Tight turning circles need to be avoided.

Stairs: In all car parks, there are significant numbers of patrons who refuse to use lifts, and so all stairs should be designed to a high standard to accommodate this, or should be alarmed and only accessible in the event of a fire.

Routes: Vehicular and pedestrians routes need to be segregated e.g. by painted walkways and separate signage schemes. Designs need to allow for wheelchairs immediately adjacent to lift lobbies and without a need to cross vehicle routes.

Signage: Conventional car parks should include significant provision for large illuminated signs for both pedestrian routes and for vehicular circulation routes.

Scale: The size or capacity of a car park needs to be directly related to the likely peak demands for parking in the immediate vicinity of the site. Patrons will not normal walk more than 180 meters from their car to their destination.

Space Size: The dimensions of spaces need to relate to the size of the vehicles expected to use the facility. The current standard of 2.4m x 4.8m spaces is quickly being overtaken by increases in car sizes and the increased use of long doors which require more room to open properly.

Usage: Busy short stay car parks in provincial towns can have an average stay of less than 60 minutes, while average stays in City Centre car parks are 2.5 to 3 hours. This can result in average cars per space of 8 to 10 per day, while in city centers it can be only 3 or 4 cars per space per day. Good barrier systems can accommodate 200 to 250 cars per hour.

Vehicle Alignment: At car park entrances and exits, it is essential to allow sufficient room for cars to enter the lane and then align themselves with entry ticket machines. This usually requires that there be at least two vehicle lengths (10m) of straight lane in front of the barrier. Lanes should be only as wide as likely vehicles require, as overly wide lanes mean that drivers cannot reach ticket dispensers from their cars.

Absolute Height: All cars must be capable of getting through the entry under the height restrictor. In a single deck car park there are no significant height issues other than absolute height of the car. When ramps are involved a whole new range of issues arise.

Length/Height: As cars move from the level up or down a ramp, the combination of length and height is key to whether the roof of the car hits the concrete ceiling or cross beams, or whether the bottom of the car scrapes floor at the top of the ramp.

Load Factor: A car which enters a car park with a heavy load, down on its axles, and attempts to leave unladen, is likely to collide with a cross beam. A flatbed truck entering with a long ladder lay flat, but later repositioned so that it sticks out or up, may face the same problem.

Aerials: Cars with telescoping aerials can pose a problem going in the aerial is down and nobody notices a problem. As the car leaves the driver switches on the radio and up goes the aerial to intercept the beams and trusses. Whip aerials get under the entry barriers and batter the light boxes and signs.

Design and Material Considerations: Few of the design and material considerations of conventional underground parking lots may be summarized as below;[5] [6] [7]

- Selecting the structural system;
- Good design practices for all types of construction; and designing for loads;
- Provisions for forces and deformations; and joints, cracks and crack control;
- Drainage planning and design; and corrosion resistance;
- Fire performance (rational design); and future expansion; lighting protection;
- Security (life/safety considerations);
- Specifications for materials, construction, and means and methods.

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[5] ***Parking Facilities***. *<http://www.wbdg.org/design/parking.php>*

[6] *M. Childs. 1999.* ***Parking Spaces: A Design, Implementation, and Use Manual for Architects Planners and Engineers.*** *McGraw Hill, New York.*

[7] *S. R. Thomas. 2000.* ***The Practice of Watershed Protection.*** *Center for Watershed Protection. Ellicott City, USA.*

For durable parking structure, the material considerations may be summarized as;

- Concrete; additives (silica fume, corrosion inhibitors, and admixtures);
- Epoxy coated reinforcing; concrete sealers and waterproofing systems;
- Membranes; cover of reinforcing; joint sealing;
- Protection of embedded hardware;
- Sloping for adequate drainage (durability design for targeted service life);
- Special considerations for precast / pre stressed concrete;
- Lateral load-resisting systems with cast in place concrete (post-tensioned systems);
- General life cycle costs and service life expectation.

Basement Parking Areas: The Basement Parking space type refers to parking located below grade within an occupied building. First and foremost, parking structures in basement must provide for the safe and efficient passage of automobiles as well as visitors to and from their vehicles. Therefore, attention should be given to providing the maximum driver visibility possible at all turning points along the roadway.[8]

Additional Structural Requirements: Below grade extension of the building structure to accommodate basement parking is required. This involves additional excavation, structural frame, floor slabs above, sloped vehicle access ramps, and basement perimeter walls and partitions separating parking from other building enclosed areas. Typical structural floor construction is 4000psi 6" concrete slab with welded wire fabric designed for a live load of 80 lb/ft^2, and with a ramp slope of no more than 5.5%.[9]

Signage and Way finding: Signage should indicate all major internal pedestrian access points as well as external major roads and buildings. In basement parking, pavement markings are reflective paint and traffic control signage is usually reflective metal with minimum 5" high letters.

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[8] *M. Childs. 1999.* ***Parking Spaces: A Design, Implementation, and Use Manual for Architects Planners and Engineers.*** *McGraw Hill, New York.*

[9] ***Parking Basement.*** *< http://www.wbdg.org/design/park_basement.php>*

Ventilation: The parking area is generally supplied with uncondition ed air utilizi ng multiple speed fans, preferably i nterlocked with carbon mono xide detectors tied into an alarm syste m. 1~1/2cfm/ft^2 capacity and 100% exhaust a ir coordinated with th e supply a ir system is recommended.

Security Protection: Beyond parking management, several security measures are incorporated into typical basement parking spaces to ensu re the security of visitors. These generally include: uniform lighting coverage, preferably with energy efficient light fixtures; closed circuit television (CCTV) cameras; card reader access control for vehicle entrance doors; concrete filled protective bollards to protect vehicle entry keypads; and hydraulic lift wedge type barriers for egress cont rol. Also crit ical is security control of access fro m the parking area to other occupied areas of the building either through termin ation at a security screening in the main lobby or through access control at the elevator or stair entrance . Elevator l obbies are usually tempered safety glass panel s with glazed exterior doors contain ing keyed lever lockset with panic release bar.[10]

Drainage and Storm Water Management: Water runoff from vehicles is typically dealt with in basement parking spaces by insta lling trench drains with cast iron covers at all vehicle entrance/exit points, sand and oil traps at all storm drain discharge points, and floor area drains at every low point.

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2.3 Conventional Car Park Types:

There are different conventional car parking types based on unique stru ctural architecture for the use of space. These include;[11]

[10] ***Parking Basement.*** < *http://www.wbdg.org/design/park_basement.php*>

[11] ***Car Parking Types and Control Systems***
<*http://www.parking-info.com/basicPage.php?page=data/data_controlEFCG.html*>

Table 2.1: Conventional Car Park Types

Car Pak Type	Definition
Multi storey	A parking structure th at houses cars above ground level (above grade) on more than one level. If the structure also has parking decks below ground level it still forms part of this group.
Surface	An area of land at grou nd level (at grade), generally surfaced with concrete or bitumen based products and marked with car bays (stalls)
Underground	A structure below ground level (below grade) often below another non parking structure, sometimes below open ground either landscaped or laid out as a car park (parking lot)
Single deck	This is a pa rking structure with a single deck a nd may have parking laid out below.
Roof	A purpose built parking deck at the roof level of a structure used for a purpose other than parking
On street	Parking spaces on the highway either controlled by meter, pay and display machine or permit holders only

In different type of und erground car parkings, movements of vehicles between floors can be divided into three types, as mentioned below; [12] [13] [14]

[12] ***Design multiple storey car parks***. *<http://en.wikipedia.org/wiki/Parking_garage>*

[13] ***Ramps in car park***. *<http://www.parkingireland.ie/art1.htm>*

[14] ***Vehicles lifts***. *<http://www.katopark.com/custom.htm>*

Table 2.2: Vehicle Movement in different Garage Types

Movements	Garage Type	Description	Popularity
Interior ramp	Straight Ramp	Straight: high radient	High
	Circular Ramp	Curve: low radient	
Exterior ramp	Straight Ramp	Straight: high radient	Medium
	Circular Ramp	Curve: low radient	
Vehicle lift	Electro hydraulic scissor lift	Vertical or Horizontal	Low
	Full auto electro hydraulic cable lift		
	Mechanical vehicle lift		

2.4 Capacity & Size

The size or capacity of a car park needs to be directly related to the likely peak demands for parking in the immediate vicinity of the site. Patrons will not normal walk more than 180 meters from their car to their destination. The dimensions of spaces need to relate to the size of the vehicles expected to use the facility.[15] The current standard for parking define the space for car may have maximum length 4.8meters, maximum height 2.0meters, maximum width 1.9meters and in case of multilevel underground parking the maximum weight should not exceed 2500Kg. The capacity of the underground parking lot depends upon number of features, like location, usage, and cost effectiveness.

[15] ***Car Park Design.*** *<http://www.parkrite.ie/design1.htm>*

2.5 Time

The time it costs a tenant to park and retrieve their car in a conventional parking lot depends (but is not limited to) these aspects:

- Type of parking garage;
- Number of spaces;
- Number of floors;
- Number of exits/entrances.

At first the car enters the parking structure. On average (depending on the above factors) the cruising time before a tenant finds a spot in off-street parking is about 50 seconds (In on-street parking it is stated as 30 seconds).[16] On top of this there is a parking time, which is the time it takes for the tenant to park their car in the spot. This again depends on the size of the lot, and the driver's ability to park in it. Then there is the time it takes for the tenant to walk from his or her car to the exit of the parking garage.

The retrieval time will depend on the same time it takes to walk back to the car, and remove it from its lot. Then the time to exit the garage is dependent on the driving distance to the exit, and the number of people in line waiting to exit. Depending on the method of payment, the time will be increased as well. Payment at the exit could result in longer queues at the exit. Payment before entering the car will result in a longer time to get back to your car.

2.6 Costs

Cost of parking: Cost of parking car is different depending on types of car park, places. For most car parking, the charges have been quoted by the hour, and assume that the average motorist parks their car for 2-3 hours. For places such as airport car parks we have included a section on "overnight" parking, which gives the charges per day of car parking (assuming you park your car for 2-3 nights). The table below shows all the data that has been collected so far

[16] *Anthony P. Crest, Mary S. Smith. 2001.* ***Parking Structures - Planning, Design, Construction, Maintenance & Repair****. Third Edition.*

on car parking charges in UK, showing where the car parking location is, what sort of car park it is, and how much you have to pay to park.[17]

Table 2.3: Costs for Different Car Park Locations (UK)

Location of Car Park	Type of Car Park	Parking Charge	Units
Cambridge	Street Parking	£0.60	per hour
Cambridge	Multistorey Car Park	£2.00	per hour
Oxford	Street Parking	£1.00	per hour
Oxford	Multistorey Car Park	£2.50	per hour
London	Street Parking	£1.50	per hour
London	Street Residential Parking	£100	per year
Heathrow Airport	Airport Parking	£10	per day
Gatwick Airport	Airport Parking	£8.30	per day
Glasgow Airport	Airport Parking	£6.30	per day
Luton Airport	Airport Parking	£7.50	per day

Construction cost for Parking: Parking facility construction costs are affected by size per space, size and shape of site (small and irregular shaped sites increase unit costs), number of levels (more levels increase unit costs), topography (slopes and poor soil conditions increase

[17] ***Car Parking Price in UK*** <*http://www.whatprice.co.uk/car/parking-charges.html*>

costs), design (exterior aesthetic t reatments can increase costs), an d geographic location. Structured parking involves a trade off between construction and land costs. Prices for Garage parking include hard and soft costs. Soft costs: project planning, design, permits and financing are calculated as 18% of total hard costs. The costs per garage space are given below;[18]

Table 2.4: Construction Cost for Conventional Car Parking

Calendar Year	Garage with Retail Shell			Garage without Retail shell		
	Hard Costs	Soft Costs (18%)	Total	Hard Costs	Soft Costs (18%)	Total
2000	$13,483	$2427	$15,910	$12,809	$2306	$15,115
2001	$14,292	$2573	$16,865	$13,578	$2444	$16,022
2002	$15,150	$2727	$17,877	$14,392	$2591	$16,983
2003	$16,059	$2890	$18,949	$15,256	$2746	$18,002
2004	$17,022	$3064	$20,086	$16,171	$2911	$19,082
2005	$18,044	$3247	$21,291	$17,141	$3086	$20,227

Operation and Maintenance: Operation and maintenance costs in clude cleaning, lighting, maintenance, repairs, security, landscaping, snow removal, access control (e.g., entrance gates), fee collect ion (for priced p arking), enforcement, insurance, labor and administratio n. Parking facilities requ ire resurfacing and repav ing every 5-10 years, and parkin g structures major reconstruction or replacement after 20-40 years, with higher maintenance cost s in areas with harsh climates, particularly with frequent salt exposure. Parking structures may require elevators, fire control an d mechanical ventilatio n. Private p arking facilities must pay taxes and provide profits. The incr emental cost of fee collection ranges from less than $50 annually per vehicle for a simple pass system with minimal enforcement, to more than $500 per space for

[18] ***Cost per garage space*** *<http://www.tp.ohio-state.edu/planning/southcampparkplan/AppendixD.htm>*

facilities with attendants or automated control systems. A 1998 study found that typical annual costs per space ranged from about $200 for basic maintenance of a surface lot, up to $800 for a facility with tollbooth attendants. A 1996 survey found that commercial parking operating expenses average about $500 annually per space, about half of which is associated with fee collection and security.[19] [20] [21]

Table 2.5: Different Costs Associated with Conventional Car Parks

Parameter	Cost
Cashiering Salaries & Benefits	$ 120
Management and supplies	$ 85
Security	$ 67
Utilities	$ 58
Insurance	$ 16
Routine maintenance	$ 19
Structure maintenance	$ 50
Snow removal	$ 4
Equipment maintenance	$ 11
Other expenses	$ 64
Total	**$ 494**

Environmental and Indirect Costs: Paving land for parking imposes environmental costs, including green space loss (reduced landscaping, farmland, wildlife habitat etc.), increased impervious surfaces, and related stormwater management costs, heat island effects and aesthetic degradation. The construction of parking facilities, particularly parking structures, consumes large quantities of energy and results in significant emissions of greenhouse gases

[19] *John Dorsett (1998), "**The Price Tag of Parking**," Urban Land, Urban Land Institute (www.uli.org), May 1998, pp. 66-70.*

[20] *ITE (1999), **Transportation Planning Handbook**, ITE (www.ite.org) p. 535.*

[21] Todd Litman (2002), **Evaluating Transportation Land Use Impacts**, <www.vtpi.org/landuse.pdf>.

from the production of concrete and steel. Ongoing operations and maintenance also requires energy and materials that have environmental costs.[22] [23]

2.7 Environmental Aspects

Ventilation: Motor vehicles are a constant source of pollutants, the most significant being gasoline, motor oil, polycyclic aromatic hydrocarbons (PAHs), and heavy metals. Many parking lots are also significant sources of trash which ends up in waterways. The underground parking garages are generally supplied with unconditioned air utilizing multiple speed fans, preferably interlocked with carbon monoxide detectors tied into an alarm system.[24]

Lighting Standards: Old recommendations on internal lighting standards e.g. of 50lux, have long ago been discarded by the industry and replaced by minimum standards of 100lux and 250 to 350lux at entrance/exits. White fluorescent bulbs provide the best quality of light. Tungsten lamps generally give yellow tints and leave "cave" effects unless used in high densities. Lighting in stairwells and lobbies need to be to a very high specification to minimize perceptions of personal isolation.[25]

Ice Prevention: Radiant heaters or slab heating coils are incorporated into the structured parking structure to prevent ice build-up, which could cause dangerous driving/walking conditions within the parking structure.[26]

Sound Emissions / Vibrations: The surrounding walls of the underground parking facility shall cover any sound emission of more than 40dBA emanating outside the structure, measured at

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[22] *Bryan Pijanowski (2007),* ***Parking Spaces Outnumber Drivers 3-to-1, Drive Pollution and Warming****, Purdue University <www.purdue.edu/uns/x/2007b/070911PijanowskiParking.html>*

[23] *Donald Shoup (2005),* ***The High Cost of Free Parking****. Planners Press <www.planning.org>.*

[24] ***Novenco car park ventilation system.*** *<http://www.novenco.de/NovencoWebGermany.nsf/Broschuren/$FILE/Reference_objects_int.pdf>.*

[25] ***Car Park Design.*** *< http://www.parkrite.ie/design1.htm>.*

[26] ***Parking Outside / Structured*** *<http://www.wbdg.org/design/park_outside.php>*

the boundaries of the parking lot. Not only sound but also vibrations resultin g from the machinery need to be considered f or potential negative impact to the rest of the building and their influence shall be kept to a very minimum.[27]

Water Drainage Handling: Drainage facilities shall be constructed and designed in such a manner that there is no stagnation of water in the parking ga rage. The internal drainage system shall be co nnected to main common drain at an appropriate location in accordance with the existing networks. The table below shows the comparison of environmental aspects of different car parks type.

Table 2.6: Environmental Impacts (to be dealt with) for Conventional Underground Parkings

Car Park Type	Gas Emissions	Water Management	Lightning	Ventilation
Above surface	Low	Medium	Low	Low
Underground	High	High	High	High
On street	Low	Medium	Low	Low

Treatment of parking facility pollution: Traditionally, the runoff has been shunted directly into storm sewers, streams, dry wells or even sanitary sewers. However, larger municipalities now require constructio n of stormwater management facilities for new lots. Typical facilities include retention basins, infiltration basins and percolation trenches. Some ne wer designs include bio retention systems, which use plants more extensively to absorb and filter pollutants.

2.8 Risks

Security Protection: Beyond parking management, several security measures are incorporated into typical structured parking structures to ensure the se curity of visitors. These generally include: uniform lighting coverage, preferably with energy efficient light fixtures, closed

[27] ***Robotic Parking Systems.*** *<http://www.robopark.com/corporate.html>*

circuit television (CCTV) cameras, card reader access control for vehicle entrance doors, concrete filled protective bollards to protect vehicle entry keypads and ticketing systems, and hydraulic lift wedge type barriers for egress control. Also critical are the exterior security systems, including CCTV cameras and building security flood lighting, related to the protection of elevator lobby space, stairs, and other support spaces accessible from the parking area. Depending on the level of protection desired, consider ballistic glazing for the parking booths.[28]

Fire and Life Safety: The fire suppression system using the sprinklers is installed in all of the structured underground parking areas. However, the testing on the regular basis must be performed (weekly or monthly) in order to maintain the health of system.

Proper notification systems, lighting, and signage are required to facilitate safe and speedy evacuations during an emergency. This is usually accomplished with proper fire alarm wiring, pull stations, strobes, annunciators, and exit signage.

Ice Prevention: Radiant heaters or slab heating coils are incorporated into the structured parking structure to prevent ice build-up, which could cause dangerous driving/walking conditions within the parking structure.

2.9 Legal Aspects

Building Codes: Relevant building codes and standards for underground parking garages are defined and well implemented by the regional and national authorities in most of the countries. These codes define the construction and facilities requirements for the structure. However the codes vary with the region to region, but most of them ensure the high standards of person safety and environmental aspects.[29] [30]

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[28] ***Robotic Parking Systems.*** *<http://www.robopark.com/corporate.html>.*

[29] *Anthony P. Crest, Mary S. Smith. 2001. Parking Structures - Planning, Design, Construction, Maintenance & Repair. Third Edition.*

[30] *World Bank.* ***Hazards of Nature, Risks to Development: An IEG Evaluation of World Bank Assistance for Natural Disasters****. Washington, DC: World Bank, Independent Evaluation Group, 2006. <http://www.worldbank.org/ieg/naturaldisasters>.*

Handicapped Parking: In many countries handicapped parking spaces are required in parking garages. The standards vary between 3% and 10% of the parking areas. In hospitals or medical centers, the parking area for handicap is in high percentage of total space, where as in shopping centers or offices underground parking garages, it can be as low as one third of the total space.[31]

Accidents: An accident happening on private property is in some countries an entirely private matter, resulting in private investigations. In other cases, where the parking garage is considered public land, the police will be involved.[32]

2.10 Services

Few of the car park management and operational services include;

1. Parking reservation online system;
2. Project management of IT solutions, from specification to installation and operation;
3. Parking shop management with fully trained staff;
4. Vehicle clamping, removal, storage and disposal;
5. CCTV enforcement of parking and moving traffic offences;
6. Security measures to ensure safe environments for drivers and their vehicles;
7. Management of season tickets, contract parking and permits;
8. Repair, replacement and upgrade of equipment as required;
9. Asset management and planned maintenance programs.

2.11 Enhancements

There are number of enhancements made in the underground parking garages, however, few of them are highlighted here;

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[31] ***ADA Accessibility Guidelines for Buildings and Facilities*** *(ADAAG)* *<http://www.access-board.gov/adaag/html/adaag.htm#4.6>*

[32] *House of Lords - Clark (A.P.) and Others. Smith & General Accident Fire & Life Assurance Corporation PLC Cutter v. Eagle Star Insurance Company.* *<http://www.publications.parliament.uk/pa/ld199798/ldjudgmt/jd981022/clarke01.htm 1998>*

Control system by using optimal character recognition (OCR): The main objective is to develop a system that can display the current parking information of the car park. The information displays include the available space and total space of the car park lot. The system uses client server environment. The administrator will monitor the system and the database from the server side. Furthermore the parking information will be displayed static based on the database shared by the server. Server application and database will be stored in the server. The result shows the system is capable to save log record that will ease tracking parking user, updating user and parking credit database as well as monitoring availability of parking spaces.[33]

Impulse Ventilation system: Impulse technology has established itself as the new standard in car park ventilation. Impulse ventilation systems are an alternative to ducted mechanical extract systems, overcoming many of the problems associated with such systems. An impulse fan is similar to a tunnel jet fan, but has a reduced diameter in order to maximize headroom. It comprises an axial fan with inlet and exhaust attenuators and any necessary guards and flow distribution control devices. Besides, conventional car parking has been improved with construction method to increase space and minimize the distance between two cars.[34]

[33] *Document of 2008 International Conference on Computer and Electrical Engineering:* ***A Study of Car Park Control System Using Optical Character Recognition*** *(page 866).*

[34] ***Natural and Mechanical Ventilation.*** *Colt International Licensing Limited 2007.*

3.0 Automated Underground Parking Garages

3.1 Introduction

With the enlargement of urban cities, increasing car populations, and increasing traffic, the subsurface is an attractive alternative for engineers to look at solutions to the problem of parking cars. The innovation of automated underground parking is a relatively new phenomenon, which is supposed to decrease the size of structures and increase time efficiency. This can result in higher profits, less traffic congestion in cities, and greater parking capacities. Also, the risk to the car in terms of theft and damage can also be considerably lower.

3.2 Types of Underground Smart Parking Systems

There are different types of automated underground car parking systems based on unique structural architecture for the use of space. These include;

Table 3.1: Types of Underground Smart Parking System

Car Park Type	Definition
Semi Automatic (Mechanized)	The underground car park system, in which the automation is incorporated with the manual operations. The parking lot may or may not be accessible for the customers.
Automatic	The underground parking system, in which the whole systems are operated by incorporation of mechanical and electronic subsystems, and the control system control all the parking activities. The access of the user or customers is limited. Normally, users park the cars on the parking shaft and come back afterwards to receive it from receiving point.
Intelligent (Robotic)	The new type of underground parking system, in which ICT technologies also play a vital role. The parking place can be reserved from home or offices, and helps to reduce the problem in finding parking places. The details of the parking spaces in the garage are continuously updated on the sign boards. All the parking is totally automated, with no human interface. The user can also update the status of parking place; time online or by using his/her telemetric system.

3.3 Basic Requirements of Underground Automated Parking Garages

Continuous Power Supply: Continuity of power supply is the first consideration. The automated parking facility must be such as to provide facilities to simplify inspection, testing, maintenance, cleaning, and general repairs at site.

Protection for externals: Special care must be taken to make the enclosed equipment proof against entry of rats, lizards and other creeping reptiles, which may create electrical, short-circuit. All ventilation opening shall have suitable screen protection.

Equipment classification: All equipment installed must be complete with approved safety devices wherever a potential hazard to personnel exists and with provision for safe access of personnel to and around equipment for operational and maintenance functions.

Tool Collection System: A modern state of the art toll collection system such as mechanized parking ticket issuing machine may be designed for computation and collection of toll. The toll must be collected from the vehicles at the exit point. A mechanized barrier gate shall be designed and synchronized with the toll collection system for regulating entry/exit of vehicles into and out of the parking area. The tool collection system can be manned or unmanned but in order to reduce cost and interaction for staff, it should be unmanned.[1]

Entry and Exit Points: The entry/exit point of automated parking facility is located away from the traffic junctions and exit locations. The entry/exit of vehicles is used, so that it does not hinder pedestrian movements and shall under no circumstances be from walkways. The minimum clear width of Entry Area is designed according to the respective needs and leaving adequate space to the left and right of the car for passengers to leave/enter the car. Adequate area for queuing of the in bound and out bound vehicles is usually provided. The Entry areas are equipped with sensors to ensure the right positioning of the vehicle to be transported as well as determine the presence of oversized vehicles, protruding mirrors or racks, which exceed the size limitations of the system.[2]

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[1] ***Development Of Multi Level Parking At Vaishali In Ghaziabad.*** *June 2009. Under Integrated Urban Rejuvenation Plan.*

[2] ***Robotic Parking Systems.*** *<http://www.robopark.com/corporate.html>.*

Motion Detectors and CCTV: Motion detectors and CCTV cameras or similar devices are installed inside the Entry and Exit Areas to ensure that no person or animals are inside the Entry and Exit Areas or the vehicle when the machine starts moving. Cameras are also installed to record digital photos of the physical condition of the car entering and exiting the premises. The images are also helpful to automatically locate cars with image processing methods for drivers with a lost ticket and to validate damage claims.[3]

Fire Fighting Facilities: The developer also incorporates the automatic fire suppressing and fighting equipment and facilities conforming to relevant standards and the applicable rules and regulations. Specifically, the fire fighting system must be adequate to control petroleum fires. Construction of automated parking facility structure with non-combustible material without a specified fire resistance also supports the fire prevention and risks of fire. In addition, those portions of the facility used for the transport and / or storage have finish of non-absorbent, non-combustible material.

Graphical User Interface / On-Line Support: The automated parking facilities are furnished with a Graphical User Interface or Human Machine Interface. This interface is usually positioned in the control room. The GUI shows the geometry of the entire System with occupancy and all installed machines moving in real time. The GUI used are normally capable of running mechanized without human assistance; it incorporates the manual and maintenance mode and the capability of system diagnostic of all critical mechanical, electrical and electronic equipment.

Automation and Process Control: The automation system is suitable for acquiring data / information from various systems / sub-systems and processes them to execute the functions as required for the operations. The level of automation satisfies the requirements of the promised specification for the parking system like human interface, ticketing, tracking of the car, choice of least time, retrieval and metering etc. A computer CPU with appropriate software acts through the PLC.[4]

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[3] *L.E. Mimbela and L.A. Klein. 2000.* ***A summary of vehicle detection and surveillance technologies used in intelligent transportation systems****. Federal Highway Administration, Intelligent Transportation Systems Joint Program Office. <http://www.fhwa.dot.gov/ohim/tvtw/vdstits.pdf>*

[4] *A.A. Mathijssen. 2007.* ***Verified design of an automated parking garage****. Lecture Notes Computer Sciences. 4346: 165-180.*

Table 3.2: Requirements of Underground Smart Parking Systems

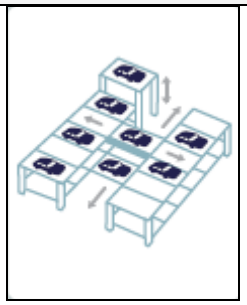
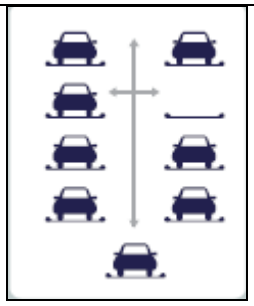
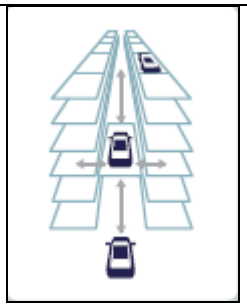
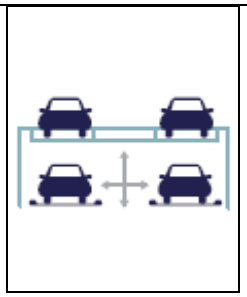
Car Pak Type	Continuous Power Supply	Protection for externals	Tool Collection System	Entry and Exit Points	Motion Detectors and CCTV	Fire Fighting Facilities	GUI / On-Line Support	Automation & Process Control	System Complexity
Semi Automatic	Medium	High	Manual	Single entry and exit point	Low	High	Low	Low	Medium
Automatic	High	High	Automatic / Unmanned	Single entry and exit point	High	High	High	Medium	Medium
Intelligent (Robotic)	High	High	Automatic / Unmanned	Multiple / separate entry and exit points	High	High	High	High	High

Requirements: High, Medium, or Low.

3.4 Type of Underground Automated Parking & Location

The type of parking and location of the parking plays an important role in order to decide the usability the other benefits for commune. The type of the underground automated parking area is also dependant on the technology or shape of the car parking facility. Also, the location of the parking area plays an important role, so that the long term investment should be profitable and based on cost benefit analysis.[5]

Table 3.3: Types and Locations of Underground Automated Parking System

Car Park Configuration	Application	Pictures
Cart Type	Buildings and lands for middle & large scale	
Elevator Type (Independent)	Buildings for small & middle scale. • Hospital • Office • Hotel (It is proper for operators of parking business).	
Elevator Type (Built in)		
Jack Type (HIP Type)	Buildings for large scale: • Department Store • Shopping Center • Hotel & Theater • Office Building	
Puzzle Type	Buildings for small scale.	

[5] ***Klaus Multiparking.*** *<http://www.klausparking.com/product/fully-automatic/layer-systems.aspx>*

3.5 Capacity & Size

The vehicles (maximum dimension 5.25m long, 2.2m wide and 1.7m high) with mentioned dimensions are parked in the underground parking area. The normal capacity and size of underground automatic parking varies from 60 to 1200 parking places, with varying levels from 2 to 9. However, the system capacity can be increased with the up-gradation of the system technologies.[6] [7]

Table 3.4: Capacity and Size of Underground Automated Parking Configurations

Car Park Configuration	Capacity	Dimensions	Number of Lifts
Cart Type	More than 50 cars, 18 Cars per floor, Max (8 floors)	Length : 5160 mm Width : 2100 mm Height : 1550 mm Weight : 2100 kg	1 or 2(max)
Elevator Type (Independent / Built-in)	10 – 50 cars 50 cars in 45m^2 per unit or floor	Length : 5200 mm Width : 2250 mm Height : 2000 mm Weight : 2200 kg	Rail for Elevator
Jack Type (HIP Type)	More than 100 cars (138 cars maximum at 6 levels)	Length : 5150 mm Width : 2100 mm Height : 1550mm Weight : 2100 kg	Multi level, Multi row lifts Separate entry and exit bays
Puzzle Type	5 to 7 cars	Length : 5050 mm Width : 2040 mm Height : 1550mm Weight : 1850 kg	One lift or cart, underground or at ground

The capacity and size also varies with the technology we are using for development of parking area. The automated and semi-automated garages are of fixed capacity that varies with the space available. The additional benefit of robotic car parking is the optimization of

[6] ***Parking System Solutions.*** *<http://www.parkingsystemsolutions.com/multi-floor/>*

[7] ***Urban Parking Concepts.*** *<http://www.urbanparkingconcepts.com/docs/automated-parking-solutions.html>*

space, in which the proximity sensors are used to vary the height of the parking plate, on to which the car is placed. With the variation of the parking space in accordance to the dimensions of the vehicle, creates more space. These parking facilities are normally variable in capacity and depend upon the efficiency and accuracy of robotic or automated system. World's largest underground parking is being constructed by Microsoft in Redmond, USA, with the capacity of over 5000 cars. The world's largest operational underground automated parking system is in Copenhagen, with the capacity of 840 cars. The world's largest robotic underground parking is in Hessaloniki, Greece, with the capacity of 1100 Vehicles.[8] [9] [10]

3.6 Time

The time component for automated parking is significant in determining the capacity of a parking, and the size of the parking garage, which in turn also determines the retrieval time. The retrieval time for the car is normally between 1 and 2 minutes, depending on the capacity of the parking area, number of cars and bays. The retrieval time depends on the complexity of automation and mechanization in the system, and the type of parking.

Table 3.5: Retrieval Time for Different Parking Configurations

Car Park Configuration	Capacity	Retrieval Time	Number of Entry / Exit Bays
Cart Type	More than 50 cars, 18 Cars per floor, Max (8 floors)	48sec ~ 80sec	1 or 2(max)
Elevator Type (Independent / Built-in)	10 – 50 cars 50 cars in 45m^2 per unit or floor	30sec ~ 60sec	2 entry bay and 2 exit bay
Jack Type (HIP Type)	More than 100 cars (138 cars maximum at 6 levels)	38sec ~ 40sec	1 entry bay and 1 exit bay
Puzzle Type	5 to 7 cars	60sec~120sec	1 lift or cart for both entry and exit

[8] ***Microsoft Car Parking.*** *<http://www.forbes.com/2008/04/10/parking-automobiles-retail-biz-logistics-cx_ew_0410parking.html>*

[9] ***Copenhagen Car Parking.*** *<http://www.grontmij-carlbro.com/en/Menu/News/News+archive/CopenhagenUndergroundParking.htm>*

[10] ***Greece Car Parking.*** *<http://www.skyscrapercity.com/archive/index.php/t-132853.html>*

The integrated motion control system from GE services 324 spaces with a retrieval time of 60-90 seconds. No attendant is required in this garage, where 35 independently operated robots transport the vehicles to their lots.[11] Cesena Automatic Underground Parking System, Italy has 108 spaces and offers a retrieval time of 50 seconds.[12]

Table 3.6: Retrieval Time for Different Underground Parking Types Associated To Capacity

Car Park Type	Vehicle Retrieval Time	Capacity
Semi Automatic (Mechanized)	50sec 15min (Manual)	108 cars
Automatic	38sec 10~30min (Manual)	138 cars
Intelligent (Robotic)	30 ~ 60sec	50~300 cars

3.7 Costs

Automatic multi-storey car parks provide lower building cost per parking slot, as they typically requires less building volume and less ground area than a conventional facility with the same capacity. However, the cost of the mechanical equipment within the building that is needed to transport cars internally needs to be added to the lower building cost to determine the total costs. Other costs are usually lower too, for example there is no need for an energy intensive ventilating system, since cars are not driven inside and human cashiers or security personnel may not be needed.[13] [14] [15] [16]

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[11] ***Robotic Parking Systems.*** *<http://www.robopark.com/corporate.html>*

[12] ***Cesena Automatic Underground Parking System, Italy.*** *<http://www.mingdynastyhk.com/2008/06/cesena-automatic-underground-parking-system-italy/>*

[13] ***Robotic Parking Systems.*** *< http://www.robopark.com/corporate.html>*

[14] ***Cesena Automatic Underground Parking System, Italy.*** *<http://www.mingdynastyhk.com/2008/06/cesena-automatic-underground-parking-system-italy/>*

[15] *Carl Walker (2009), "**Parking Structure Cost Outlook for 2009**," Industry Insightes, Carl Walker, First Qr.;* <www.carlwalker.com/press/newsletters>

Table 3.7: Costs for Automated Underground Parking Types

	Cost for 600~620 Underground Car Parking (Approx. Million USD)				Cost Per Space (USD)	
Car Park Type	**Land Cost**	**Const. Cost**	**Soft Cost**	**Develop. Cost**	**Const.**	**Operation**
Semi Automatic (Mechanized)	12	7.5	0.4	20	32,000	395 per Month
Automatic	12	15	0.7	28	20,000	265 per Month
Intelligent (Robotic)	6	9	0.4	15	23,000	338 Per Month

3.8 Environmental Aspects

While automated parking facilities require considerably more electric power than their conventional counterparts, the management and maintenance aspects are much less labor intensive, resulting in cost savings overall. In addition, conveying technology eliminates the need to move cars manually through the parking structure, eliminating polluting vehicle exhaust emissions throughout the parking structure.[17]

However, the emissions of gases like CO, SOx and Hydrocarbons are reduced, so the ventilation system is not used for these purposes. However, in order to maintain the humidity, temperature and flow of the fresh air, the ventilation system is incorporated. The antirust protection systems are incorporated within the parking facility. The optimal temperature for the operation of automated system is ensured by incorporating different systems. As the access of users is limited (only for special purposes), the illumination needs are also reduced, saving the electricity usage cost in long terms.[18]

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[16] *Appendix D:* ***Estimated construction cost for parking of South campus parking project.***

[17] **Urban Parking Concepts.** <http://www.urbanparkingconcepts.com/docs/automated-parking-solutions.html>

[18] *Todd Litman (2008),* ***Parking Requirements on Housing Affordability****, VTPI.*<www.vtpi.org/park-hou.pdf>.

The water management system is incorporated, to avoid the induction of water from walls of the parking garage or from bottom. The p umping system at the bottom of parking continuously try to main tain the water level in the surround ing soils to ensure stability of structure, and also the discharge of water from the parking garage itself.

Table 3.7: Environmental Impact for Automated Underground Car Parking Types

Car Park Type	Gas Emissions	Water Management	Lightning	Ventilation
Semi Automatic (Mechanized)	Yes (Low)	Yes (Medium)	Yes (Medium)	Yes (Medium)
Automatic	Yes (Low)	Yes (Low)	Yes (Low)	Yes (Low)
Intelligent (Robotic)	No	Yes (Low)	Yes (High)	Yes (Low)

Requirement: Yes / No

3.9 Risks

Few of the risks mitigated with underground automated parking facilities include; [19] [20]

- Automated car parking limits danger to people injury, nor a ny carbon monoxide risk because people don't have to go inside underground levels;
- Internal safety of car is assures by the anti-intrusion, fir e-fighting, anti-flood and ventilation system that are computer controlled;
- The systems are used required to be reliable and safety to control;
- The parks reduce environmental pollution be cause car movement performed thanks to engine switched off;

[19] *A.A. Mathijssen. 2007.* ***Verified design of an automated parking garage****. Lecture Notes Computer Sciences. 4346: 165-180.*

[20] *Z. Razak and Others. 2009.* ***Car park system: A review of smart parking system and its technology****. Information Technology Journal. J., 8: 101-113. <http://scialert.net/fulltext/?doi=itj.2009.101.113&org=11>*

3.10 Legal Aspects for Parking Mishandling

Accidents: Since cars do not drive in this parking lot, the risk of accidents between multiple cars or single car accidents is very small. This reduces the amount legal issues that might arise at the parking lot from car accidents. Accidents that are significant are accidents that occur because of mishandling of a vehicle, malfunction of the lift, etc. These accidents would be the responsibility of the parking lot management, rather than the car owners'. [21]

The implementation of the automated system like robotic intelligent system, eliminates the chances of accidents inside the car park, however, few of the accidents like electric short circuiting, natural disasters or malfunction of sequence (software) can be reduced by employing better construction and implementation techniques.[22]

3.11 Services

Automated garages may continuously develop automatic services to customers such as an automatic payment station, or a booking and managing, guidance service. Automatic payment station: with this system, driver can settle his parking fee without an intervention of a cashier. Before leaving the parking the customer introduces his ticket into the bar code scanner. The LCD display shows the calculated parking fee to be paid. The customer pays the indicated amount. The new services like electric charging for hybrid cars are also employed in the robotic park systems, for the reasonable costs.[23] [24] [25]

3.12 Enhancements

In recent year, the automatic car parks have been enhanced by software of control system, new techniques:

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[21] *A. Nordmark. 2005.* ***Access way to underground space: Present status of access ways to underground space with examples of spatial requirements****. ITA Working Group.*

[22] *S.A. Shaheen and Others. 2005.* ***Smart parking management field test: A bay area rapid transit (bart) district parking demonstration.*** *<http://pubs.its.ucdavis.edu/download_pdf.php?id=44>*

[23] ***Revolutionary Parking System.*** *<http://www.e-globalparking.com/>*

[24] ***Parking: outside/structure*** *by WBDG staff. <http://www.wbdg.org/design/park_outside.php>*

[25] *Richard Willson (1995), "****Suburban Parking Requirements; A Tacit Policy for Automobile Use and Sprawl,****" Journal of the American Planning Association, Vol. 61, No. 1, Winter 1995, pp. 29-42.*

Electronic and Robotic Systems: The robotic system employs the highly automated system, with the number of proximity, photo electric and piezoelectric sensors. These sensors are integrated together by the control system, and help to control the operation of the mechatronic systems.

ICT: The use of information and communication technologies in the new innovation, by which a customer can reserve the parking place online using his i-phones. Along with this, the permanent or frequent users can be provided with the scan cards to avoid the delay in the car retrieval, and they can reduce the car retrieval time.[26]

SLS: is software system designed to simulate the build and operation of a Robotic parking system. It provide valuable information as queuing and retrieval time and is an excellent tool in anticipating and managing the impact of a car park system on surrounding road network. To run SLS, the physical characteristics are entered to establish it's configure. Then the traffic profile - frequency and volume - is added. These two elements allow simulation to be run, and report to be generated. Once the reports have been analyzed, change to the system can be made to optimize performance and simulations re-run to test revisions, until the optimum solution is arrived.[27]

[26] ***Press Release Source.*** *AutoMotion Parking Systems. AutoMotion Introduces First Fully Automated Parking Garage In N.Y.C. < http://www.automotionparking.com/>*

[27] ***Skypark Control System*** *<http://www.fataskyparks.com/documents/controlsystem.pdf>*

4.0 Evaluation

4.1 Introduction

The most advanced option for an underground automated garage is the intelligent robotic garage. Although it has a slightly higher construction and maintenance cost per car compared to the automatic garage, it scores better on capacity, retrieval time, number of exit bays, environmental aspects, and degree of automation. In this evaluation chapter, the two types of underground parking garages i.e. automated garages (intelligent, automatic, and semi-automatic) will be compared with a conventional garage. At the end of the chapter the individual points of comparison are weighted and ranked in a multi criteria evaluation, which shows the overall preferred garage.

4.2 Basic Requirements

The basic requirements for both of the systems are same, however, continuous controlling, supply of electricity, proper maintenance and other additional technological installations rises the automated underground parking garages development cost. The additional benefits, however, compensate the one time investment cost in long term cost benefit analysis.

Table 4.1: Comparison of Basic Requirements for Underground Parking Systems

Basic Requirements	Conventional Underground Parking System	Automated Underground Parking System
Clearances (Head / Side)	Important (as per standards)	Not Important
Number of Lanes	Important (as per standards)	Not Important
Lightning Requirements	Important (as per standards)	As and When Required
Offices and Main Lobbies	Required	Not Required
Routes and Signage	Required	Not Required
Space Size	Fixed	Variable
Fire Protection Systems	Important (as per standards)	Variable
Electricity Requirements	Without Backup supply	24 Hours with Backup supply
Lifts	For people only	For vehicles and People (Maintenance)

4.3 Capacity & Size

The size and capacity of the conventional underground parking system is comparatively large, but along with this the space occupied by the parking garage is also big. Automated parking systems require up to 50% less space to handle the same number of vehicles compared to conventional, ramped parking facilities. Depending on the specific configuration of the parking system, automated parking facilities also require less space. These factors make automated parking garages a competitively priced, flexible alternative to conventional parking facilities. The minimum space requirements for single carousel systems are 100 x 100 feet. 180 x 180 feet is required for double carousel garages.

Maximum capacity: The largest above ground conventional parking lot at the moment is the West Edmonton Mall in Alberta, which wraps around the mall and has 20,000 parking spaces. Some might say that the parking lot is not a single structure and claim that Seattle's Airport garage is the largest, with 13,000 spaces under one roof.[1] The largest underground conventional parking lot is currently being constructed by Microsoft and has 5000 spaces. Nevertheless, the scale is much larger than the largest automated parking lot, which has 765 spaces and is located in Dubai.[2]

4.4 Costs

Construction Costs: An automated parking lot will need less volume per car. So, when determining the size of the garage with a certain capacity, the automated garage will be smaller than a conventional one. This will translate directly into lower construction costs. Less land-use resulting from this will further reduce costs. When building a circular automated garage (which is common), extra costs should be taken into account compared to the often rectangular conventional parking lots. The construction of an automated garage will be lighter, because the floors will not have to be drivable by cars. This will decrease the amount of concrete and asphalt used, further reducing costs.[3]

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[1] ***The World's Largest Parking Lots.*** *Forbes, October 2008.*
<http://www.forbes.com/2008/04/10/parking-automobiles-retail-biz-logistics-cx_ew_0410parking.html>

[2] ***Park It Here****, Robotic Parking Systems Inc, March 2010.*
< http://www.roboticparking.com/email/2010Mar.html>

[3] ***RingGo and Verrus Payment Systems.****<http://www.apcoa.co.uk/payment-systems/>*

Maintenance Costs: Costs will be saved in automated parking on various installations such as ventilation and lighting systems. Also, personnel working in security and cashier service will not be necessary. The automated parking garage, although, does need a lift to transport the cars. This will also require engineers to maintain the lift, and hence in an automated garage one pays more for the electric control system and advanced equipments.[4]

Table 4.2: Comparison of Costs for Underground Parking Systems

Costs	Conventional Underground Parking System	Automated Underground Parking System
Land Space (area) for 200 cars	Space : 4,200m^2	1,200m^2
Construction cost for 200 spaces	USD 45 Million	USD 11 Million
Construction cost per Space	USD 225,000	USD 55,000
Operating Cost per Space per Month	USD 130	USD 60 ~ 90
Management Cost per Year	USD 86,000	USD 0
Security Cost per Year	USD 30,000	USD 0
Depreciation of Garage per year	3 ~ 5 %	16 %

4.5 Time

Retrieval times are generally shorter in automated garages. So far, this still depends on the size and capacity of the garage. But, as technology improves, these times are further reduced. Also important in automated parking is the time a tenant of the parking garage will spend to get his car back. This is not always equal to the retrieval time. If there are multiple tenants retrieving their car at the same time, there will be a waiting period before some customers cars can begin to be retrieved.

[4] ***Revolutionary Parking System*** <*http://www.e-globalparking.com/*>

This disadvantage will increase waiting time significantly, especially in garages with particularly high peaks in usage at certain times (rush hour). In conventional underground garages the waiting time also increases with more intense use, with the difference being that tenants can retrieve their vehicles at the same time, and then wait in a queue at the exit. The type of user will have a significant impact on the retrieval time for the user. The users can be split into 3 categories. These categories are defined by the location of the garage;

- A garage located near a shopping center would mean a steady flow of incoming and outgoing traffic;
- If the garage is located by an office building, flows of traffic would be great during rush hour and low outside those hours;
- A garage under a residential building would mean a low flow of traffic at different times of the day.

There are no solid figures on this, but one could reason that a garage near an office building would create the longest retrieval times for the user. At the moment, retrieval times are around 1 to 2 minutes per car in existing garages. With a large demand for parking during peak hours, this will result in a queue as tenants wait to have their car parked. The waiting time could then be as long as 10 to 15 minutes as the tenants wait for their turn.[5]

4.6 Environmental Aspects

The conventional underground parking garages are more influenced by the environmental hazards, like rain, temperature changes and humidity. Along with this, the environmental risks of the underground parking garages are higher due to presence of gaseous emission, and direct contact of users. The automated underground parking garages are less influenced by the environmental changes, however, both of the systems incorporates appropriate systems or technology, in order to have better parking environment.

[5] ***Automated car park (TreviGroup).*** *<http://www.trevigroup.com/viewdoc.asp?co_id=203>*

Table 4.3: Comparison of Environmental Aspects for Underground Parking Systems

Environmental Aspects	Conventional Underground Parking System	Automated Underground Parking System
Illumination System	Very Important (as per standards)	Used as and When Required
Emissions of Gases (CO2)	39.5 Ton per Year	6.7 Ton per Year
Additional Fuel Burning	4036 Gal per Year	689 Gal per Year
Ventilation System	Very Important	As and When Required
Water Management Setup	Very Important (critical)	Important
Ice Prevention System	Important (depends)	Not important
Sound / Noise	Medium (or sometimes High)	Low (negligible)

4.7 Risks

Compared to conventional park, automatic one limits risk for drivers and vehicles, because no requirement of vehicles driven insight. Moreover, automatic one becomes environmentally-friendly thanks to engine switched off when moving. Both types of parking lots, when constructed under ground level, will have the risks of construction safety such as settlement, leakage, etc, but also social safety (the effect to adjacent buildings).

Table 4.4: Comparison of Risks for Underground Parking Systems

Risks	Conventional Underground Parking System	Automated Underground Parking System
Theft and Vandalism	High	Low (negligible)
Personal Injury	Medium	Low (negligible)
Fire	Medium	Low
Flooding	Medium	Low (negligible)
Accident	Medium	Low (negligible)
Security Risks	High	Low (negligible)
Damage and Dent to Vehicle	Medium	Low (negligible)

4.8 Legal Aspects

Accidents: Where accidents such as dents and scratches are usually the problem of the car owner, the responsibility lies with the service provider in the automated garage. Because the robot will place the car, a malfunction causing a dent or scratch will likely be the fault of the operator of the facility, and not the car owner. It is significant to point out, though, that the risk of scratching or denting the vehicle is significantly less. Accidents causing damage to the facility is also considerably less in automated garages.

Environment and Building Codes: Environmental and building standards will have to be met in both conventional and automated garages.

Handicapped Parking: Where spaces must be allocated in conventional parking facilities, automated garages do not have to do this, because the entry and exit point is the same for every car. This will save a few spaces in the automated parking garages, which are not always filled to capacity in conventional garages.

4.9 Services

Both types of garages provide drivers not only easy payment services but also managing their parking status via mobile, Internet. These systems are designed to display the necessary information of available space, time parking and price of parking.

Table 4.5: Comparison of Services for Underground Parking Systems

Services	Conventional Underground Parking System	Automated Underground Parking System
Payment System	Manual	Online / Automatic
Hybrid Car Charging	No	Yes (Intelligent Systems)
Waiting Rooms	Not Required	Required (often)
CCTV (Security Services)	Required	Required (often)
Facilities (Shops / Intercom / Toilet)	Required	Not Required

4.10 Enhancements

Conventional parking is a very developed idea with few significant enhancements to be made. Enhancement can be made by improvements to the ventilation and lighting systems, although there would not result in significant changes in costs, space, or time. Automated parking is in its infancy and improvements to the system are conceivable.

With a system where you can call the automated garage ahead of time, retrieval time will be almost eliminated for the tenant, because the car will be ready to go when you arrive at the facility. Such a service would only be possible in an automated garage parking systems. The improvements to software and retrieval technique would decrease the retrieval time of automated parking.[6]

4.11 Construction Methods

Conventional underground parking lots may be constructed in many different ways. Due to the fact that construction of underground parking lots are often constructed in urban environments, the buildings around and above the parking lot pose the biggest problem. Especially in the Netherlands, where the soil has a relatively low bearing capacity and the ground water level is high, the risk of damaging surrounding buildings is high.

Main differences between conventional and automated parking lots are sizes of parking spaces, required ramps and roads for driving, and installations. All three of these have a direct influence on the construction and maintenance costs as well as the construction method. The size advantage of automated parking is due to the fact that the placing of cars in their lots does not require space a turn radius, hence allowing smaller parking spaces. Ramps and roads are not necessary in an automated garage, because cars don't drive in it.

It also allows for lighter constructions of parking spaces. In some cases steel frames have been used. Installations such as ventilation and lighting aren't necessary in some areas of the automated parking lot, further reducing construction height. The lifts in automated parking lots do require extra space.[7] [8]

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[6] **Automated parking**. http://en.wikipedia.org/wiki/Multistorey_car_park#Automated_parking

[7] ***Cesena Automatic Underground Parking System, Italy.*** *<http://www.mingdynastyhk.com/2008/06/cesena-automatic-underground-parking-system-italy/>.*

[8] *COWI A/S. 2008.* ***Underground Structures****. Engineering Services Firm. Copenhagen, Denmark.*

Table 4.6: Comparison of Construction Technologies for Underground Parking Systems

Construction	Conventional Underground Parking	Automated Underground Parking
Technology (Major)	Civil Construction	Civil, Electronics, Mechanical, ICT
Preferred Location	Under buildings	Separate Locations
Time (108 cars facility)	depends on number of factor	6 ~ 9 Months (depends on number of factor)

4.12 Multi-Criteria Evaluation

In table 4.7, the criteria for comparison are evaluated against one another to determine their individual weights for basic criterion under focus.

A : Capacity
B : Size
C : Time
D : Costs
E : Environmental Aspects
F : Risk
G : Service
H : Enhancement possibilities

This method compares each criteria and assigns them a **1** when they are more significant than the other, and a **0** when less. The results will then be translated to a weight out of 100. It will determine the importance of the criteria.

Table 4.7: Individual Weight Calculation for Different Criterion

	A	B	C	D	E	F	G	H	Total	x 2	%	Weight
A		1	1	0	1	1	1	1	**6**	12	0.21	**21**
B	0		0	1	1	0	1	1	**4**	8	0.14	**14**
C	0	1		0	1	0	1	1	**4**	8	0.14	**14**
D	1	0	1		1	1	1	1	**6**	12	0.21	**21**
E	0	0	0	0		1	1	0	**2**	4	0.07	**7**
F	0	1	1	0	0		1	0	**3**	6	0.11	**10**
G	0	0	0	0	0	0		0	**0**	1	0.02	**2**
H	0	0	0	0	1	1	1		**3**	6	0.11	**11**
Total										**57**	**1**	**100**

Below, the different types of parking lots are graded out of 10 on how they perform on each category. The grades will be based on research done on each of these criteria as shown in the previous chapters. The grades will then be multiplied by the weight and added to form a total grade.

Table 4.8: Evaluation of Different Underground Parkings as per Criterion

Criteria	Weight	Conventional Underground Parking	Automated Underground Parking
Capacity	21	7	5
Size	14	5	9
Time	14	6	7
Costs	21	5	8
Environmental Aspects	7	5	6
Risk	10	8	4
Service	2	4	8
Enhancement possibilities	11	4	8
Total	**100**	**573**	**665**

The results of this multi-criteria evaluation show that when judged on the aforementioned aspects the underground automated parking system scores significantly higher.

5.0 Conclusions and Recommendations

Conventional parking garages are near the end of their development. With countless examples around the world of conventional underground parking structures it is clear that, in order to meet rising demand for parking, there should be innovations that increase both capacity and size of parking lots. Looking for a cost-effective alternative to conventional parking is a priority. One of these new types of parking lot is the automated parking garage.

Intelligent robotic garages can offer similar capacities while using less volume to do so. When capacities are between 100-800 cars, existing structures show decreases in retrieval times when compared to conventional parking lots. Costs per parking space, as shown in this report, can be reduced by a factor of 4. This is a significant amount, which is mainly attributed to the decrease in volume needed and the decrease in concrete needed.

Automated garages also have structural benefits. They require less space for the same capacity as a conventional parking lot. Light weight steel frames can be used instead of heavy concrete decks, and ramps and drive aisles can be omitted. Automated parking garages need fewer personnel, lower insurance and lower facility maintenance costs. It saves on expenses for ventilation and lighting as well. The main operational costs arise from the high-tech lift that transports the car to its lot.

The maximum capacity of conventional parking lots exceeds the current maximum on intelligent robotic parking structures. With further development of the automation process the maximum capacity can certainly increase, but until that point conventional parking structures still offer lager capacities.

Automated parking garages are a relatively new innovation, and are still in their early stages of development. Although there are certainly many existing automated and mechanical garages, improvements to new system are still very much under development. Automated parking garages can further be improved by incorporating the features of intelligent parking systems, and further advanced features of conventional parking systems. These include the implementation of proximity sensors to detect and display the available spaces for parking. The

online parking features will further help the customers to reserve the place for their parking, with some costs variance for online services. Secondly, the entry and exit services may further be improved by providing the remote controller to the customer that enables the customer to call the call at exit point, when he/she wants.

With Intelligent Robotic parking being a relatively new innovation, it brings with it higher risks of unforeseen problem arising. Because conventional parking garages are almost fully developed, the many risk are known. This idea will certainly not be lost to the user. Parking tenants are used to driving their car to their spot, where they know it is located. In the new automated garage tenants will be asked to leave behind their vehicles. When retrieving their vehicles they will have to wait for it to be returned to them. This may make the tenant feel uncomfortable, although this may improve over time as people get used to the new system. This may cause people to stay away from automated garages and go to conventional ones instead.

A consideration that must be made when designing an automatic parking garage is the type of users that will use the garage. This consideration must, of course, also be made when designing a conventional parking lot, but it has a bigger impact on an automated parking garage. The type of user will have a significant impact on the retrieval time for the user. A garage located near an office building would result in a high demand at peak hours and could result in long queues and waiting times. This would have to be resolved by using more lifts, creating more entry points, or possibly price management.

The advantage of using the intelligent robotic system as opposed to the alternatives is that multiple entry and exit bays are possible. The fact is that automated parking garages are an innovative idea that is safe, user friendly, and reduces access and retrieval time (which continues to improve). Vehicles are stored in a safer environment with less risk of damage, theft or vandalism. These are all advantages to the user.

The safety, water management, fire protection system, and anti corrosion systems need a more focus and further improvements for automated underground parking systems. The further study on these issues with focus on cost factor will be helpful; for improvement and innovation in the technology for optimal use of underground space, that will be safe, cost effective and most advantageous.

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