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Driving change: Factors influencing smart/automated parking system adoption in Thailand

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Abstract: This study aims to explore the determinants of automated parking systems (APS)/smart parking systems (SPS) adoption among small and medium-sized enterprises (SMEs) in Bangkok. The study examines the influence of technology trust (TT), environmental consciousness (EC), and perceived risk (PR) on commuter behavioral intention (BI). The model also addresses the critical moderating role of parking space availability (PSA). Structural Equation Modeling (SEM) was used on 469 responses collected from SME commuter employees. The findings identified facilitating conditions (FC) ($\beta = 0.473$) and TT ($\beta = 0.359$) as the strongest direct APS/SPS adoption drivers, followed by EC ($\beta = 0.186$) at a significant practitioner level, while, unexpectedly, PR's negative influence on APS/SPS adoption intention was not significant. Finally, the moderating test results indicated a significant strengthening moderating effect of parking space availability (PSA) on the negative influence of price value (PV) on PR, and an unexpected weakening moderating effect of PSA on the positive influence of FC on TT at a high customer demand level, to an insignificant extent. The results provide a refined theoretical model of technology adoption in highly demanding urban contexts, along with actionable recommendations for policymakers, providers, and SMEs in the APS/SPS sector, to inform the development of sustainable urban mobility solutions.
Keywords: *Environmental consciousness, Perceived risk, Smart parking, Technology trust, Thailand, UTAUT2.*

1. Introduction

The sustainability of urban transport is one of the most pressing problems in rapidly expanding Asian megacities, where unprecedented car ownership and a finite supply of land exacerbate congestion and a parking shortage. Parking problems have been largely ignored in Bangkok for over four decades, during which time an explicit and comprehensive parking policy has also been absent [1]. Unlike Singapore or Hong Kong, Bangkok lacks a cohesive parking policy, has fragmented SME-owned land parcels, and is plagued by informal parking practices. These conditions make behavioral rather than infrastructural barriers more decisive.

Additionally, inefficient parking systems not only cause congestion on urban roads where capacity has remained constant but also waste fuel, increase emissions, waste time, and lead to a significant number of accidents that directly impact UN Sustainable Development Goal (SDG) 11 on sustainable cities and communities [2]. Solving these interrelated challenges relies on innovative infrastructure technologies that maximize land use while encouraging low-emission mobility. Among these, automated parking systems (APS) [3] and smart parking systems (SPS) [4, 5] have proven to be a successful solution [6].

While APS/SPS technologies have proliferated in dense cities such as Singapore, Seoul, and Tokyo [7], their diffusion has been limited in developing economies [8]. In the Thai context, behavioral factors, rather than technical ones, often present an adoption barrier, particularly among small- and medium-sized enterprises (SMEs) that characterize the commercial real estate landscape.

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Thai urban SMEs often occupy low- to mid-rise office buildings with limited space and inefficient parking, which directly impacts business operations, employee satisfaction, and environmental performance. Understanding user and management acceptance of APS/SPS and related automated systems in this setting is necessary to upscale and diffuse these sustainable transportation solutions [9].

The success of any smart urban technology depends not only on its technical feasibility but also on user acceptance and organizational readiness [10, 11]. The Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) provides a robust framework for explaining adoption behavior by integrating constructs such as performance expectancy, effort expectancy, social influence, facilitating conditions (FC), and price value (PV) [12]. However, studies indicate that contextual variables such as technology trust (TT), perceived risk (PR), and environmental consciousness (EC) substantially shape behavioral intention in infrastructure technologies [13]. For the adoption of APS in Bangkok's SME offices, these constructs are expected to play a decisive role in influencing employee attitudes and managerial decisions.

Despite an expanding body of literature on smart mobility and APS [14] empirical research on the acceptance of APS/SPS remains scarce, especially in developing urban contexts. Prior studies have emphasized technical optimization and system reliability but have neglected mainly socio-behavioral and organizational determinants of adoption. This gap is particularly pronounced in Southeast Asia, where cultural, infrastructural, and economic conditions differ substantially from those in Western contexts [15].

A review of recent Scopus-indexed literature reveals three significant gaps: limited empirical analysis of APS adoption in developing economies. Most studies focus on engineering or optimization aspects [16], neglecting behavioral and organizational factors that influence user intention.

Underexplored integration of sustainability constructs within technology acceptance models. Few works explicitly connect environmental consciousness with UTAUT2 variables to assess sustainable technology adoption [17].

The neglected moderating role of organizational context, such as PSA or vehicle availability, influences technology trust (TT), perceived risk (PR), and APS behavioral intention (APSBI) [18].

Addressing these gaps, this study extends the UTAUT2 framework by incorporating TT [13, 18] and EC while examining parking PSA constraints as a moderating factor. This integration enhances UTAUT2's explanatory power and aligns the study with the mission of sustainability, bridging the gap between technology adoption and sustainable transport policy.

Bangkok’s unregulated SME-driven parking ecosystem amplifies uncertainty and environmental costs, justifying the inclusion of TT (trust in unfamiliar automation), PR (risk in high-value asset handling), and EC (sustainability-motivated adoption) as critical behavioral filters.

This research contributes theoretically by advancing the integration of sustainability-oriented variables into technology adoption models, providing a more holistic understanding of behavioral intention in infrastructure technologies. Practically, it offers evidence-based insights for urban mobility policy [6] supporting Thailand’s shift toward compact, low-emission urban development. By focusing on SMEs, an often-overlooked segment in sustainable transport planning, the study highlights how digital and infrastructural innovation can enhance urban efficiency while reducing environmental footprints.

2. Literature Review and Hypotheses Development

This section presents the conceptual framework for the study's model development, while reconceptualizing TT, EC, and PR as contextual mediators that convert utilitarian perceptions into behavioral intentions under urban scarcity. This interactional framing goes beyond additive models by embedding psychological and sustainability mechanisms into infrastructural decision-making.

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2.1. The UTAUT2 Model and its Extension for APS

The UTAUT2 is a prominent model in technology adoption research, synthesizing elements from eight prior theories [11]. Its core constructs, including PE, EE, SI, FC, and PV, provide a solid foundation for understanding the drivers of APS behavioral intention (APSBI).

However, for complex, infrastructure-heavy technologies like APS/SPS in an organizational context, a direct application of UTAUT2 is insufficient. APS/SPS adoption entails significant financial investment, operational integration, and concerns regarding safety and reliability [19]. To address this complexity, we extend UTAUT2 by integrating three critical mediating constructs: technology trust (TT), environmental consciousness (EC), and perceived risk (PR) [18].

One pivotal contextual moderator, parking space availability (PSA), is a proxy for parking demand pressure. This integrated model offers a more nuanced and contextually grounded understanding of the adoption drivers for APS in Bangkok's SMEs.

2.2. Performance Expectancy (PE)

Performance expectancy refers to an individual's belief in how much using a technology will help them achieve gains in job performance. In the APS context, this relates to expected benefits such as time savings, reduced search-for-parking congestion, and improved parking reliability [20, 21]. A system's perceived performance is foundational for building confidence in the technology and aligning it with broader organizational values, such as sustainability. A high-performing APS demonstrates practical efficiency, which can reinforce the value of environmentally conscious decisions. Therefore, we hypothesize.

H_1: Performance Expectancy (PE) positively affects APS Technology Trust (TT).

H_2: Performance Expectancy (PE) positively affects Environmental Consciousness (EC).

2.3. Effort Expectancy (EE)

EE refers to the ease with which individuals can use a system [11]. For APS, this involves the intuitiveness of the user interface and the simplicity of the parking/retrieval process. A system that is easy to use reduces cognitive load and operational uncertainty, which are critical for fostering a sense of reliability and dependability, the foundations for trust.

H_3: Effort Expectancy (EE) has a positive effect on APS Technology Trust (TT).

2.4. Social Influence (SI)

Si refers to the extent in which users perceive what is important to others (e.g., management, peers, industry leaders) believe they should adopt the new technology [11, 22]. This influence is potent in collectivist cultures and within organizational hierarchies [23, 24]. Endorsements from relevant groups can enhance legitimacy and trust in the technology, as well as influence internal values. When leadership champions APS for its sustainability benefits, it can increase individual employee engagement.

H_4: Social Influence positively affects Technology Trust of APS.

H_5: Social Influence has a positive effect on Environmental Consciousness.

2.5. Facilitating Conditions (FC)

Facilitating conditions refer to the idea that technical and organizational infrastructure exists to support a system's use [25]. For an SME, this includes access to capital, reliable technical support, and the necessary physical infrastructure for integration. Strong organizational commitment and resource backing are vital for reducing uncertainty and building trust in complex technologies. Furthermore, strong enablers often directly predict intention in an organizational adoption context, representing the tangible means by which behavior can be executed.

H_6: Facilitating Conditions (FC) positively affect APS Technology Trust (TT).

H_7: Facilitating Conditions (FC) positively affect APS Behavioral Intention (APSBI).

2.6. Price Value (PV)

Price value is the consumer's cognitive trade-off between the perceived benefits of the application and its monetary cost [26]. A positive price value (benefits outweigh costs) is crucial in the cost-sensitive SME context. A favorable cost-benefit analysis can positively frame the adoption decision, aligning it with the principles of innovative resource management and long-term efficiency, thereby enhancing EC. Conversely, a high PV can also mitigate financial concerns, directly reducing the PR associated with the investment.

H_8: Price Value (PV) positively affects Environmental Consciousness (EC).

H_9: Price Value (PV negatively affects the Perceived Risk (PR) of using APS technology.

*2.7. Technology Trust (*TT)

Trust reflects a user's confidence in the reliability, functionality, and safety of automated technology [27]. For an APS, which takes complete control of a valuable asset (the vehicle), trust is not merely a facilitator but a prerequisite for adoption. Other perceived benefits become moot without a foundational belief in the system's dependability.

H_{10}: Technology Trust (TT) in APS positively affects APS Behavioral Intention (APSBI).

2.8. Environmental Consciousness (EC)

Environmental consciousness is an individual's awareness of ecological issues and a willingness to act pro-environmentally [28]. As APS is marketed as a sustainable solution that reduces emissions from idling cars and optimizes land use, an individual's pro-environmental attitude can be a direct and powerful motivator for adoption, transcending purely utilitarian calculations.

H_{11}: Environmental Consciousness (EC) has a positive effect on APS Behavioral Intention (APSBI).

2.9. Perceived Risk (PR)

Perceived risk encompasses the potential for losses, including financial losses (such as system cost and vehicle damage), performance losses (system failure), and even safety risks [19]. A high perceived risk creates a significant psychological barrier that can directly inhibit the formation of an adoption intention, even if other attitudes are positive [18].

H_{12}: Perceived Risk of using APS technology harms APS Behavioral Intention (APSBI).

2.10. Parking Space Availability (PSA)

The organizational context, specifically the ratio of available parking to the number of cars, operationalized as parking space availability (PSA), is theorized to be a critical boundary condition that alters the strength of key relationships in our model. Scarcity (low PSA) creates a "pain point" that changes how decision-makers evaluate the technology's attributes.

H_{6a}: Parking space availability (PSA) positively moderates the relationship between facilitating conditions (FC) and technology trust (TT).

Rationale: The need for an APS is low when parking is readily available (high PSA). In this context, strong FCs (e.g., good support, resources) are a "nice-to-have" that builds moderate trust. However, under conditions of parking scarcity (low PSA), the pressure to find a solution is intense. In this high-stakes context, the same FC becomes a critical "need-to-have." The presence of organizational support is interpreted as a vital signal of the system's viability and the organization's commitment to solving a pressing problem. This amplified importance strengthens the positive relationship between FC and trust. The path from support to confidence becomes more potent when acute needs arise.

H_{9a}: Parking space availability (PSA) negatively moderates the relationship between price value (PV) and the perceived risk (PR) of using technology.

Rationale: Under normal or high parking availability (high PSA), perceiving the APS as a good value (high PV) may only slightly reduce perceived risks [18]. The situation is not desperate. However, the calculus changes in a high-demand, low-PSA scenario, where the current parking situation causes daily operational friction and increased costs. The perceived cost of inaction (wasted time, employee frustration, lost productivity) rises dramatically. In this "painful" context, a positive PV proposition becomes a powerful cognitive counterweight to risk. The high relative cost of the problem makes the solution's value more salient, amplifying its power to diminish PR. A high-pain context makes a valuable solution less risky by comparison.

2.11. Summary of the Research Model and Hypotheses

The integrated research model (Figure 1) presents a comprehensive framework for the adoption of APS. The core UTAUT2 constructs are positioned as antecedents to key mediating beliefs: PE, EE, SI, and FC contribute to TT; PE, SI, and PV influence EC; and PV mitigates PR. FC also retains a direct path to intention, acknowledging its role as a key enabler. These three mediators, TT, EC, and PR, then converge to directly determine the Behavioral Intention to adopt APS (APSBI). Crucially, the model incorporates PSA as a moderator on two theoretically justified paths (H6a and H9a), asserting that the organizational context of parking scarcity fundamentally alters how decision-makers process FC and PV.

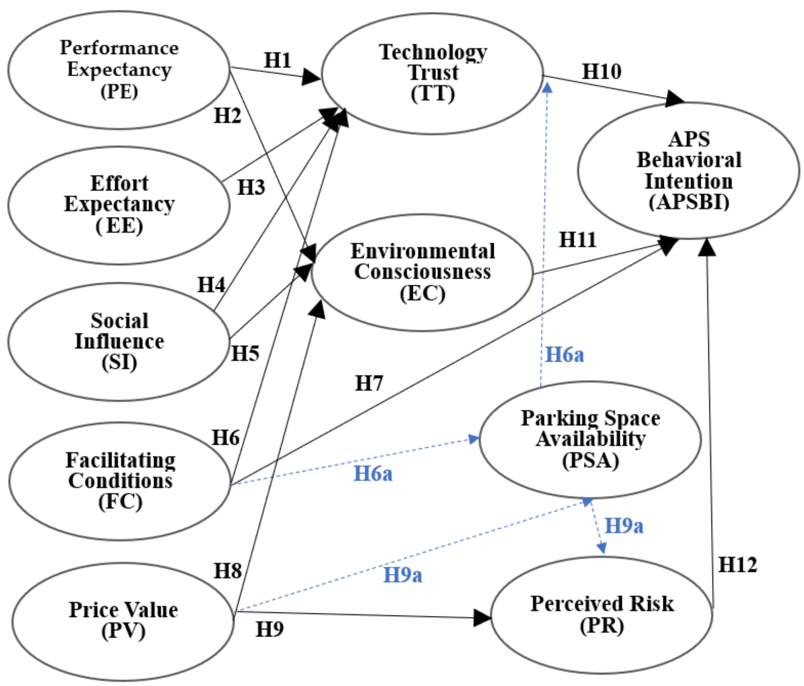

Figure 1.
The Proposed Research Model for the APS Behavioral Intention.
Note. Blue hypotheses, numbers, and blue dashed lines represent the moderating role of PSA, which is tested on the relationships between Facilitating Conditions and Trust, and between Price Value and Perceived Risk.

2.12. Research Objectives (ROs) and Research Questions (RQs)

This study aims to:

RO1. Identify and analyze the key determinants that influence the behavioral intention to adopt APS among SMEs in Bangkok.

RO2. Examine how TT, PR, and EC mediate relationships within the UTAUT2 framework.

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RO3. Investigate the moderating influence of PSA and vehicle count on these relationships.

RO4. Offer actionable insights for policymakers, urban planners, and APS providers to enhance sustainable urban mobility through technology adoption.

To achieve these objectives, the following research questions guide the study:

RQ1: What factors influence SMEs' behavioral intention to adopt Automated Parking Systems (APSBI)?

RQ2: How do TT, PR, and EC interact with UTAUT2 constructs to shape adoption behavior?

RQ3: Does organizational parking space availability (PSA) moderate the effects of facilitating conditions and price value on TT and PR?

RQ4: What strategic implications can be derived to promote sustainable transportation adoption within the SME office context in Bangkok?

3. Methods

3.1. Research Design

This study employed a quantitative, cross-sectional design using a hypothetico-deductive approach to examine the determinants of APS adoption among small and medium-sized enterprises (SMEs) in Bangkok. A structured questionnaire was used to collect data, designed to test the proposed conceptual framework based on the Extended UTAUT2 model, augmented with TT, PR, and EC as mediators, and PSA (number of vehicles and parking spaces) as a moderator.

Structural equation modeling (SEM) with IBM's SPSS Amos 21 software was applied to evaluate the hypothesized relationships and test both measurement and structural models. SEM was chosen because it allows for the simultaneous analysis of multiple latent constructs and mediating/moderating effects, providing a comprehensive test of theoretical interrelations [29].

3.2. Rationale for Construct Selection and Omission

The development of our research model was guided by theoretical parsimony and contextual relevance. While perceived usefulness (PU) from the Technology Acceptance Model (TAM) is a well-established determinant of intention, it was consciously omitted from the final model for two primary reasons.

3.2.1. Conceptual Overlap with UTAUT2's Core Constructs

A primary goal was to build upon the more comprehensive UTAUT2 framework. Within UTAUT2, the core concept of utility is captured by performance expectancy (PE) [30], which refers to the degree to which technology will benefit consumers in performing specific activities. This construct directly encompasses the utilitarian value that PU measures. Including PE and PU would introduce significant multicollinearity and conceptual redundancy, potentially obscuring rather than clarifying the model's findings. This alignment is supported by the origin of UTAUT, which was designed to synthesize and supersede elements of models like TAM.

3.2.2. Contextual Supersession by More Specific Constructs

Our preliminary qualitative exploration and literature review suggest that the drivers of APS adoption in a commercial SME context are more nuanced than the general concept of "usefulness."

The value of an APS is not just in its general utility but specifically in its ability to solve a critical resource constraint (parking space), which is more precisely captured by the power of Facilitating Conditions.

Furthermore, in a high-stakes environment involving valuable assets (vehicles), the belief that the system is "useful" depends on it being trustworthy. Therefore, TT would be a more critical and proximal mediator in the adoption of this technology.

By focusing on PE, FC, and TT, we retain the core "usefulness" logic while refining it for the specific context under investigation, enhancing the model's explanatory power and theoretical clarity.

3.3. Population and Sampling

The target population consisted of employees and managers from SMEs operating in Bangkok who utilize or are potential adopters of APS. According to Thailand's Department of Business Development, there were approximately 318,000 SMEs in Bangkok during data collection.

Given this population, the minimum sample size for SEM was estimated following Hair and Sabol [29], who suggested the need for 20 respondents per estimated parameter, thus yielding a target of at least 400 responses. After data cleaning, 469 valid responses were retained for analysis. Moreover, SMEs were selected proportionally across Bangkok's five zones to reflect varying parking pressures; inclusion was not limited to firms already facing scarcity.

1) A hybrid sampling strategy was employed;

2) Cluster sampling was used to divide Bangkok into geographical zones (Central Business District, North, East, South, and West).

3) Within clusters, simple random sampling was applied to select SMEs;

4) Respondents included both managerial and operational staff involved in facility decisions;

5) To enhance representativeness, SMEs of varying sizes and sectors (retail, services, light manufacturing) were included, ensuring diversity in parking conditions and employee demographics.

3.4. Instrumentation and Measurement

The questionnaire consisted of five sections. These included:

Demographic and organizational information - (age, gender, position, years of work, number of company vehicles, available parking spaces).

UTAUT2 Constructs - PE, EE, SI, FC, and PV. Adapted from Venkatesh et al. [11] and Tamilmani et al. [18] using 3–4 items per construct.

Mediating Variables - Technology Trust (TT) [31],

Perceived Risk (PR) and Environmental Consciousness (EC) [32].

Dependent Variable - Behavioral Intention (BI) toward APS adoption (3 items; adapted from Venkatesh et al. [11].

Moderator – Parking Space Availability (derived from the ratio of vehicles to parking spaces; categorized as No Need, Neutral, or Need).

All items were measured using a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

Minor linguistic and contextual adjustments were made to fit the SME APS context, and a translation–back–translation procedure was employed to ensure equivalence between the English and Thai versions [33]. A brief illustrated description of APS operation preceded all survey items to ensure baseline familiarity; respondents unfamiliar with APS were excluded via screening.

3.5. Validity and Reliability

An index of item-objective congruence (IOC) test was conducted with four subject matter experts (two academics, two APS industry professionals). Items with IOC values of 0.50 or greater were retained.

A pilot study of 30 SME respondents yielded Cronbach's alpha values greater than 0.70 across all constructs, confirming internal consistency [34].

Confirmatory Factor Analysis (CFA) was conducted using IBM's SPSS Amos 21 to evaluate measurement validity. The model met acceptable thresholds.

$\chi^2/df < 2.0$, CFI, TLI, NFI, IFI ≥ 0.90, RMSEA ≤ 0.05, RMR < 0.05.

Convergent validity was supported by composite reliability (CR $\geq$ 0.7) and average variance extracted (AVE $\geq$ 0.5). Discriminant validity is confirmed when the square root of the AVE exceeds inter-construct correlations. Only theoretically consistent modification indices were applied to improve model fit, following guidelines and fully reporting adjusted paths.

3.6. Data Collection Procedure

Data were collected between January and April 2025. Questionnaires were distributed to selected SME offices in person and via secure online forms. Participation was voluntary and anonymous, with no incentives provided.

Response control: A cover letter outlined the research objectives and provided assurances of confidentiality. Incomplete or patterned responses (e.g., same score for all items) were excluded, resulting in a final valid sample of 469. Nonresponse bias was assessed by comparing early and late respondents using t-tests across key variables; no significant differences were found ($p > 0.05$).

3.7. Ethical Considerations

In an effort to comply with the Declaration of Helsinki, the study was issued an exemption certificate by the authors' university. At every step, the anonymity of the participants was considered and ensured, with all interviewees informed that no information concerning their private information would be used. All other survey participants gave informed consent for inclusion before participating in the study.

3.8. Data Analysis Techniques

The hypothesized model was tested using a two-stage Structural Equation Modeling (SEM) approach with IBM SPSS 28 and Amos 21, ensuring the reliability and validity of the measurement model before examining the structural relationships among constructs.

Confirmatory Factor Analysis (CFA) verified construct validity and internal consistency [35]. Data normality, skewness, and kurtosis were examined [36], and Variance Inflation Factors confirmed the absence of multicollinearity [37]. Model fit was assessed using standard indices (χ^2/df, GFI, TLI, CFI, RMSEA, RMR), and hypotheses were evaluated at $p < 0.05$.

Parking Space Availability (PSA) served as a moderator tested via multi-group analysis. Parking-scarcity groups were classified by vehicle-to-space ratio: ≤1.0 = No Need (n=121), 1.01–1.50 = Neutral (n=101), >1.50 = Need (n=247). Measurement invariance (configural, metric, and scalar) was established prior to testing moderation through chi-square difference ($\Delta\chi^2$) analyses of the FC→TT and PV→PR paths [31].

To strengthen validity, Common Method Variance (CMV) was examined using Harman's single-factor test [38], which confirmed the absence of significant bias. The significance of mediation was verified through 5,000-sample bootstrapping [34], which provided robust confidence intervals for the indirect effects. Overall, these procedures ensured a rigorous and transparent assessment of the extended UTAUT2 model and its moderating and mediating effects.

3.9. Summary of Methodological Rigor

Table 1 provides a concise summary of the methodological rigor employed in this study, detailing the specific criteria and established benchmarks applied to ensure the strength of the analysis. The table demonstrates that the researchers' approach adhered to recognized standards across all key components, including sampling adequacy, instrument reliability, convergent validity, and model fit. Furthermore, it outlines rigorous procedures for testing moderation and checking CMV, providing a transparent overview of the comprehensive steps to validate our findings.

Table 1.
Methodological Rigor Processes.

Component	Criteria	Reference
Sampling adequacy	n = 469 > 10× no. of parameters	Hair and Sabol [29]
Instrument reliability	Cronbach's α > 0.7; CR > 0.7	Izah, et al. [39]
Convergent validity	AVE ≥ 0.5	Hair and Sabol [29]
Model fit	χ^2/df < 2.0; CFI, TLI > 0.9; RMSEA < 0.05	Hair and Sabol [29]
Moderation procedure	Configural–metric–scalar invariance	Klopp and Klößner [40]
CMV check	Harman's test < 50% variance	Howard, et al. [38]

4. Results

4.1. Respondents' Profiles

A total of 469 valid responses were retained after data screening. The sample reflects Bangkok's service-based SME economy, comprising managers and employees across retail, services, and light industries. SMEs from all five administrative zones, north, south, east, west, and central, were represented, covering 50 districts. The most represented areas were Bang Na (5.33%), Phra Khanong (5.33%), Prawet (6.40%), Bueng Kum (4.69%), and Lak Si (4.69%), ensuring balanced coverage of both central and suburban business zones.

The sample was gender-balanced (55% female, 45% male), predominantly aged 30–39 (54.6%), and highly educated (97% with at least a bachelor's degree). About 43% earned between 40,001–60,000 ฿ ($1,100–1,650). Nearly all respondents (97.7%) commuted by car, 70% owned two or more vehicles, and over 70% of firms had fewer parking spaces than vehicles. Additionally, 41% spent 5–9 minutes searching for parking, and 27% had experienced parking-related penalties or accidents, confirming the practical severity of parking issues among Bangkok SMEs.

4.2. Data Screening and Preliminary Tests

Data were screened for missing values, outliers, and normality using SPSS 28. Missing data less than 2% per item were replaced via series mean substitution. Skewness and kurtosis values fell between ±2.0, supporting normality assumptions [41]. Variance Inflation Factors (VIF) ranged from 1.08 to 3.26, indicating no multicollinearity.

Common Method Variance (CMV) was assessed [42]. Using Harman's single-factor test, the first factor accounted for 34.8% of the variance, which is well below the 50% threshold [38].

4.3. Measurement Model Validation (CFA)

The measurement model validation began with CFA to assess the reliability and validity of nine latent constructs. These included performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC), price value (PV), attitude toward the service (APSBI), technology trust (TT), perceived risk (PR), and environmental consciousness (EC).

The initial measurement model demonstrated inadequate fit to the data (χ^2/df = 3.771, CFI = 0.821, RMSEA = 0.054). To improve model fit, two key modifications were implemented. First, the perceived usefulness (PU) indicator was removed from the PE construct because its R-squared value fell below the acceptable threshold of 0.25. Second, based on modification indices, covariances between error terms of items sharing similar measurement characteristics were incorporated.

The final measurement model exhibited excellent fit across all indices (χ^2/df = 1.373, CFI = 0.981, TLI = 0.973, RMSEA = 0.020), meeting recommended thresholds for model acceptance. All factor loadings were statistically significant and exceeded 0.70. Convergent validity was established with average variance extracted (AVE) values above 0.50 and composite reliability (CR) values above 0.70 for all constructs [43].

The removed PE item was 'Using APS improves my work productivity.' Correlated residuals were added between PE2–PE3 and TT2–TT3 based on shared wording context (both measured perceived efficiency). A supplementary analysis treating PSA as a continuous moderator yielded consistent direction and significance, confirming the robustness of the results.

4.4. Measurement Invariance for Moderated Analysis

Prior to testing moderation hypotheses, measurement invariance was assessed across the three PSA groups (No Need, n=121; Neutral, n=101; Need, n=247) using a hierarchical sequence.

Configural Invariance established the same factor structure across groups (χ^2=1,298.616, CFI=0.981, RMSEA=0.020);

Metric invariance confirmed equal factor loadings across groups (ΔCFI = -0.001 from configural);

Partial Scalar Invariance was achieved after releasing certain intercept constraints ($\Delta\chi^2[8] = 18.764$, $p = 0.016$);

The establishment of partial scalar invariance confirms that meaningful comparisons of structural paths across groups are justified for testing moderating effects.

4.5. Structural Model and Hypothesis Testing

The structural model demonstrated an excellent fit (χ^2/df = 1.373, CFI = 0.981, RMSEA = 0.020) and explained substantial variance in key endogenous variables, with TT (R^2 = 0.57), EC (R^2 = 0.46), PR (R^2 = 0.31), and APSBI (R^2 = 0.63), as shown in Figure 2.

Direct Effects Results - Facilitating conditions demonstrated the most substantial direct effect on APSBI (β = 0.473, $p < 0.001$), underscoring the critical importance of organizational support for technology adoption in SMEs. TT (β = 0.359, $p < 0.001$) and EC (β = 0.186, $p = 0.003$) also showed significant positive effects on APSBI. Contrary to expectations, SI did not significantly affect EC (H5), and PR was not a significant deterrent to APSBI (H12) Table 2.

Table 2.
Direct Effects and Hypothesis Testing Results.

Hypothesis	**Path**	**β**	**p-value**	**Supported**
H1	PE → TT	0.116	0.005	**Yes**
H2	PE → EC	0.203	< 0.001	**Yes**
H3	EE → TT	0.196	0.041	**Yes**
H4	SI → TT	0.238	0.035	**Yes**
H5	SI → EC	-0.049	0.538	**No**
H6	FC → TT	0.300	< 0.001	**Yes**
H7	FC → BI	0.473	< 0.001	**Yes**
H8	PV → EC	0.553	< 0.001	**Yes**
H9	PV → PR	-0.673	< 0.001	**Yes**
H10	TT → BI	0.359	< 0.001	**Yes**
H11	EC → BI	0.186	0.003	**Yes**
H12	PR → BI	0.082	0.181	**No**

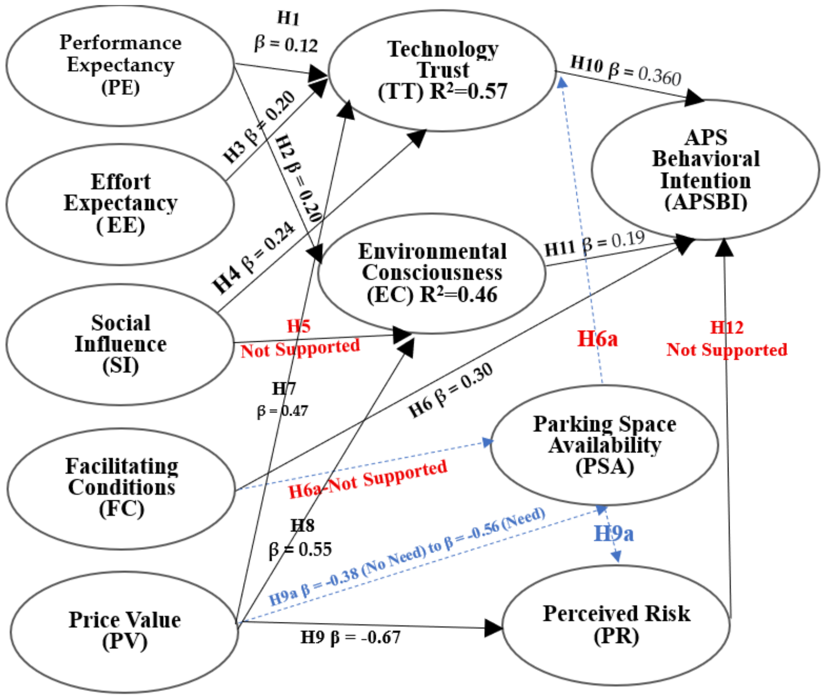

Figure 2.
The Final Research Model for APS Behavioral Intention.
Note: Blue dashed lines and hypothesis numbers indicate the supported moderating effect of PSA, which strengthens the negative link between Price Value and Perceived Risk. Hypotheses in red were not supported.

4.6. Hypothesis Testing: Moderating Effects

A multi-group analysis was conducted to test the moderating role of PSA on two key relationships. The sample was divided into three groups: 'No Need' (n = 121), 'Neutral' (n = 101), and 'Need' (n = 247). Measurement invariance tests confirmed that configural and metric invariance were established, enabling meaningful group comparisons.

The results revealed a complex moderating effect, visually summarized in Figure 3.

H6a was not supported: The positive effect of FC on TT was significantly moderated by PSA ($\Delta\chi^2 = 255.547$, $p < 0.001$), but in an unexpected direction. As illustrated in Figure 3a, while FC strongly enhanced TT in the 'No Need' group (β = 0.450), this relationship weakened in the 'Neutral' group (β = 0.272) and became non-significant in the 'Need' group (β = -0.037). This suggests that under conditions of high parking scarcity, infrastructural support alone is insufficient to build trust.

Conversely, H9a was supported: The adverse effect of PV on PR was significantly moderated by PSA ($\Delta\chi^2 = 259.149$, $p < 0.001$). The visual pattern in Figure 3b shows that the relationship strengthened from the 'No Need' group (β = -0.380) to the 'Need' group (β = -0.563), indicating that under high PSA, a positive price value becomes substantially more effective at reducing perceived risk.

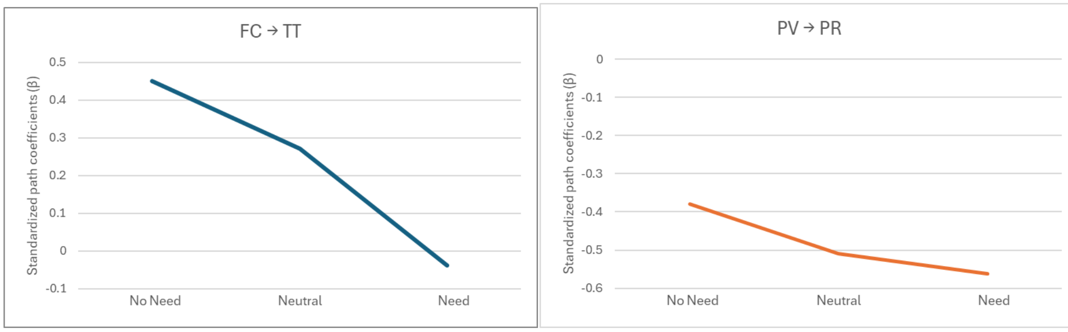

Figure 3.
Interaction Plot of Moderation Effect FC→TT and PV→PR

4.7. Mediation Analysis

Mediation analysis employed the bootstrapping technique (5,000 resamples) to estimate indirect effects; confidence intervals that did not include zero confirmed the significance of mediation. The results of the key mediating paths are presented in Table 3.

Table 3.
Results of Mediation Analysis with Bootstrapped Confidence Intervals.

Mediating Path	Indirect β	95% CI	Significant
PE → TT → BI	0.081	[0.043, 0.137]	Yes
PE → EC → BI	0.051	[0.028, 0.094]	Yes
PV → PR → BI	0.029	[0.006, 0.062]	No
FC → TT → BI	0.064	[0.037, 0.115]	Yes

As shown in the table, the paths PE → TT → BI, PE → EC → BI, and FC → TT → BI were all statistically significant. However, the path PV → PR → BI was insignificant, as its confidence interval included zero.

4.8. Explained Variance (R^2)

The model explained substantial variance in the key endogenous constructs:

- Technology Trust (TT): $R^2 = 0.57$;
- Environmental Consciousness (EC): $R^2 = 0.46$;
- Perceived Risk (PR): $R^2 = 0.31$;
- Behavioral Intention (APSBI): $R^2 = 0.63$

The strong effect of Performance Expectancy confirms that the perceived usefulness of the APS in solving parking challenges is a fundamental driver of adoption, aligning with broader technology acceptance literature. The high explanatory power for APSBI (63%) demonstrates the strength of the extended UTAUT2 model in predicting APS adoption intention.

4.9. Summary of Results

The analysis strongly supports the integrated research model, with ten of the fourteen hypotheses supported in Table 4. The findings confirm the importance of TT and EC as key mediators, revealing unexpected nuances about how PSA moderates the role of FC and PV in the adoption decision-making process.

Table 4.
Comprehensive Hypothesis Testing Summary.

Hypotheses	Relationships	Results	Key Findings
H1	PE → TT	Supported	Performance expectations build trust
H2	PE → EC	Supported	Performance links to environmental values
H3	EE → TT	Supported	Ease of use fosters trust
H4	SI → TT	Supported	Social influence builds confidence
H5	SI → EC	Not Supported	Peer pressure does not affect eco-consciousness
H6	FC → TT	Supported	Organizational support enables trust
H6a	FC → TT (Moderated)	Not Supported	Support becomes irrelevant under high demand
H7	FC → BI	Supported	Direct enabling effect on intention
H8	PV → EC	Supported	Good value aligns with environmental values
H9	PV → PR	Supported	Positive value reduces risk perceptions
H9a	PV → PR (Moderated)	Supported	Value becomes crucial under high demand
H10	TT → BI	Supported	Trust is essential for adoption
H11	EC → BI	Supported	Environmental values drive intention
H12	PR → BI	Not Supported	Risk perceptions do not deter adoption

5. Discussion

This study validated an extended UTAUT2 model to explain the behavioral intention of Bangkok SMEs to adopt APS. Integrating TT, EC, and PR as mediators, and PSA as a contextual moderator, provided a nuanced understanding of technology adoption in an urban environment characterized by severe parking scarcity. The model explained 63% of the variance in adoption intention, confirming strong predictive power. The discussion follows the four guiding research questions.

5.1. RQ1: Determinants of APS Behavioral Intention

The analysis reveals two interconnected mechanisms driving adoption: a pragmatic pathway centered on facilitating conditions (FC) and trust, and a value-oriented pathway driven by environmental consciousness. FC exerted the strongest direct influence on intention ($\beta = 0.473$), highlighting that, for SMEs with limited resources, concrete organizational and infrastructural support is not merely facilitative but essential for adoption. Technology trust ($\beta = 0.359$) was the second most powerful determinant, underscoring that confidence in a system that handles valuable assets must precede any behavioral intention.

The positive effect of EC ($\beta = 0.186$) illustrates that practical motivations are complemented by sustainability values, confirming the relevance of the Values–Beliefs–Norms framework. Many SMEs increasingly perceive environmentally responsible technologies as consistent with modern business norms, linking operational efficiency with sustainability. The non-significance of PR in predicting intention (H12) provides an important contextual insight. In Bangkok's acute parking shortage, the perceived utility of APS outweighs potential risks, illustrating how urgent urban challenges recalibrate risk–reward assessments.

5.2. RQ2: Individual and Managerial Determinants

The study clarifies how managers and employees develop the two critical mediators, TT and EC, that shape adoption behavior. Trust emerges not spontaneously but through demonstrable reliability, ease of use, and institutional assurance. Empirical evidence from prior research on automated systems emphasizes that perceived performance, transparency, and dependability underpin trust formation. The current results echo these findings: performance expectancy (PE → TT, $\beta = 0.116$) and effort expectancy (EE → TT, $\beta = 0.196$) significantly enhance trust, confirming that users must perceive the system as both valuable and straightforward to operate. Social influence (SI → TT, $\beta = 0.238$) and facilitating conditions (FC → TT, $\beta = 0.300$) further reinforce trust by signaling managerial endorsement and organizational readiness. Thus, TT in APS adoption is simultaneously a technical, social, and structural construct.

Environmental consciousness operates differently. It is strengthened through pragmatic and economic reasoning rather than social persuasion. EC increases when employees view APS as effective (PE → EC, $\beta = 0.203$) and cost-efficient (PV → EC, $\beta = 0.553$), but not through social influence (SI → EC, $p > 0.05$). This suggests that in workplace contexts, ecological concern arises from perceived functional and financial merit, not peer pressure. When APS demonstrates tangible savings in time, cost, and emissions, users naturally align those benefits with sustainability values. This reinforces that authentic ecological motivation, rather than social conformity, drives environmentally oriented adoption decisions.

5.3. RQ3: Moderating Role of Parking Space Availability

PSA significantly shapes the adoption logic by redefining how users evaluate trust and value. The moderation analysis revealed a dual effect. First, the traditional power of FC to enhance TT diminishes as parking scarcity intensifies. Under high demand, even strong infrastructural support cannot offset skepticism; users require intrinsic confidence in system performance rather than external assurances. This introduces an important theoretical boundary for UTAUT2, showing that in high-pressure contexts, institutional support has limited influence if the technology's credibility is unproven.

Conversely, the moderating effect of PSA strengthened the negative relationship between PV and PR. When parking scarcity is acute, the perceived value of APS significantly reduces risk perceptions (β shifts from –0.380 to –0.563). In other words, a strong economic rationale, cost savings, efficiency, and reduced stress, become decisive during pressing needs. The more critical the parking problem, the more users tend to reinterpret cost as an investment rather than an expenditure. These findings highlight how environmental urgency and infrastructural pressure reweight decision criteria, making value perception central and support structures secondary.

5.4. RQ4: Strategic Implications for Accelerating Adoption

Drawing on these insights, a three-pronged strategy can accelerate the diffusion of APS.

For SME management, implementation should begin with apparent infrastructural readiness and organizational commitment (FC), immediately followed by efforts to build TT through demonstrations, usability training, and pilot implementations. Simultaneously, communication should emphasize both performance and environmental benefits to activate pragmatic and value-driven pathways.

For APS providers, marketing strategies should be context-sensitive. In high-demand zones, promotional focus must shift from promises of support to proof of reliability and cost-effectiveness. Demonstrations and transparent performance metrics foster TT more effectively than abstract assurances.

For policymakers, incentives that enhance perceived value, such as tax relief or integration of APS within sustainable transport programs, can substantially boost adoption. Campaigns linking APS use to reduce congestion and emissions appeal to EC while reframing APS as a practical sustainability solution. Municipal planners could incentivize APS through tax credits for SMEs retrofitting parking, developers with density bonuses, and operators with public–private partnerships, thereby integrating APS with smart mobility networks.

Collectively, these strategies recognize that APS adoption is both a rational and normative process: users adopt when they trust the technology [44], perceiving tangible economic and environmental benefits, and operate within institutions visibly committed to the transition.

6. Conclusions

This research successfully developed and validated a holistic model of APS adoption in Bangkok's SMEs. By extending UTAUT2 with technology trust, environmental consciousness, and perceived risk, and by accounting for the decisive contextual moderator of PSA, the study contextualized the drivers of adoption. The results indicated the centrality of FC and TT, as well as EC's motivational role, and

PSA's dual, partially contradictory role. This weakened the importance of infrastructural support and strengthened the risk-alleviating role of a good value proposition. The study provides a strong foundation for the academic and practical advancement of sustainable mobility solutions among urban businesses.

Institutional Review Board Statement:

This study involved only non-vulnerable adult participants and did not require the collection of sensitive personal data. Participation was voluntary, and informed consent was obtained from all participants prior to study commencement, either electronically or in writing. The study complies with the ethical standards of the Declaration of Helsinki (revised in 2013). The research also complies with Thailand's National Policy and Guidelines for Human Research 2015, which stipulates that social and behavioral research carried out anonymously and involving no physical or psychological risk to participants is not subject to formal institutional ethics review in Thailand [45].

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Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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