Geolocation Framework using Google Maps for Secure Distance-Based Carbon Savings Stamp in Work from Anywhere Models

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Abstract. The transition toward the WFA model marks a major change in organizational operations, supported by rapid digital innovation and the increasing need for flexible work arrangements. By utilizing cloud services, virtual collaboration platforms, and secure remote access systems to enable employees to perform their task efficiently regardless of geographic location. However, this model also brings new cybersecurity challenges. Threats such as social engineering attacks, the use of personal devices outside formal security controls, and exposure to unsecured public networks. Despite these risks, adopting remote working practices also contributes to environmental sustainability. Consequently, the adoption of flexible work models not only addresses productivity demands but also delivers tangible contributions to carbon-reduction initiatives. The reduction in carbon emissions derived from employee commuting distances can be further processed into a unique digital representation. Each unit of carbon savings is assigned a unique digital stamp, serving as a code for environmentally friendly work activities. This positive impact can be assessed with greater accuracy using technological tools, such as calculating the distance between home and the central office using the Google Maps API. Through this technological integration, the study proposes a geolocation-based WFA framework that ensures security and reliability within the digital work ecosystem.

1 Introduction

The traditional office-centered work model has long dominated organizational systems, emphasizing employees' physical presence as a measure of discipline and productivity. However, issues such as traffic congestion, rising living costs, and high office maintenance expenses have revealed its inefficiencies [1]. Limited flexibility also causes work-life imbalance. These weaknesses became evident during the COVID-19 pandemic, when restrictions forced organizations to suspend office operations and shift toward remote work. Supported by digital technologies like cloud computing and online collaboration tools, the Work from Home (WFH) concept emerged as a viable solution. Over time, WFH evolved

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into the broader Work from Anywhere (WFA) model, offering employees the flexibility to work from any location while enabling organizations to sustain productivity, reduce operational costs, and access global talent beyond geographical boundaries [2].

The decentralization of work enabled by the WFA model inevitably introduces new cybersecurity vulnerabilities [3]. Threats such as social engineering attacks, the use of personal devices that fall outside established security policies, and reliance on unsecured public networks represent potential entry points for malicious actors. On the other hand, adopting remote working practices also contributes to environmental sustainability. Reduced daily commuting, particularly the elimination of office-bound travel, decreases fossil fuel consumption and lowers carbon emissions. Thus, WFA presents a dual impact: while it amplifies the complexity of digital security challenges, it simultaneously supports global environmental sustainability.

The reduction in daily commuting resulting from flexible work arrangements has been shown to significantly decrease transportation-related emissions [4]. This positive impact can be assessed with greater accuracy using technological tools, such as calculating the distance between employees' residences and the central office using the Google Maps API. Such an approach enables emission estimates to be derived from actual travel routes, thereby providing more relevant results that can be integrated into organizational sustainability reporting systems. Consequently, the adoption of flexible work models such as WFA not only addresses productivity demands but also delivers tangible contributions to carbon-reduction initiatives.

Carbon emission reductions from reduced commuting are converted into unique cryptographic digital stamps representing eco-friendly work activities. Integrated with geolocation systems, these stamps ensure secure, transparent tracking of emission savings. This approach enhances WFA productivity, strengthens data security, and builds a measurable digital ecosystem that promotes operational efficiency and environmental sustainability.

The study by Plötz et al. (2021) compared carbon emissions from gasoline- and electric-powered vehicles across countries. The research highlighted the importance of measuring emissions under real-world driving conditions, both with and without load, to produce more representative estimates. Based on average measurements, it was found that for a representative travel distance of approximately ±5 km, carbon emissions reached around 149 g CO_2/km [5]. Furthermore, recent research by Xie and Lin (2025) investigated carbon emissions using the World Light Vehicle Test Cycle (WLTC) as a standardized measurement framework. Their findings indicated that, under uniform speed conditions, gasoline-powered vehicles produced approximately 146 g CO_2/km [6]. By combining the average values from the two vehicle categories, an overall mean of 147.5 g CO_2/km was obtained, which serves as the basis for calculating vehicular emissions. Fabien's study (2022) further explains that the emissions resulting from walking and cycling activities are largely influenced by the food-to-fuel mechanism, namely the metabolic energy required by the human body. According to this study, the average carbon footprint amounts to 55 g CO_2/km for walking and 35 g CO_2/km for cycling [7]. These values will be adopted in this study as the baseline value for carbon emission calculations in the development of the proposed digital stamp mechanism.

The research conducted by Al-Asad et al. (2024) examined the performance of various hashing algorithms for data integrity, using multiple evaluation metrics. The findings indicated that the SHA family of algorithms ranked highest in maintaining data integrity, as determined by entropy analysis. The high distortion levels observed in the NMSE (Normalized Mean Square Error) and PSNR (Peak Signal-to-Noise Ratio) metrics further demonstrated SHA's capability to conceal messages effectively, making them resistant to forgery or manipulation [8]. Although the processing time of SHA algorithms was reported to be moderate compared to other approaches, the study emphasized that their primary strength lies in ensuring security and encryption integrity. In practice, SHA-256 is used as the initial encryption step to generate unique codes for each digital stamp produced in this research.

Building on previous studies, this research focuses on developing a digital stamp as a unique identifier for each WFA activity. The stamp generation process employs the SHA-256 algorithm as the encryption foundation to ensure data integrity, which is further combined with the El-Gamal optimization algorithm to strengthen both security and authentication. To achieve higher accuracy in calculating carbon emission savings, the Google Maps API is used to automate distance measurement within the geolocation system. Through this technological integration, the study proposes a geolocation-based WFA framework that ensures security and reliability within the digital work ecosystem.

2 Method

The research procedure is illustrated in the flowchart shown in Figure 1 below.

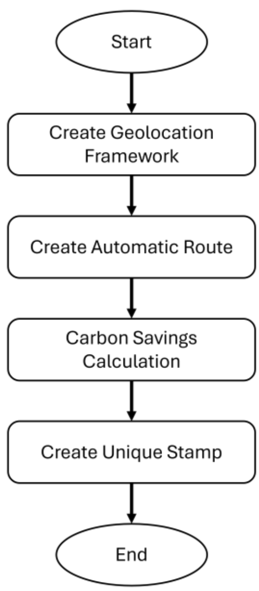

Fig. 1. Research methods diagram.

2.1 Geolocation framework

The geolocation framework is developed as a web-based application using React.js for its flexibility in building interactive, dynamic, and seamlessly integrated interfaces. Supported by the Google Maps API, the system defines two key markers: the employee's home as the origin and the office as the central work location. Automated fields display detailed WFA location data, including place name, address, latitude, and longitude, retrieved via API integration. This enables accurate mapping and structured data collection for each work activity's digital identity. The collected data can then be linked to carbon emission calculations and the generation of cryptographic digital stamps, enhancing accuracy and sustainability tracking.

2.2 Automatic route

Automatic route determination is implemented in the geolocation framework via the integration of the Google Maps API [9]. The route is designed to select the shortest path based on vehicular transportation modes, thereby producing calculations that are both efficient and realistic. Additional configuration is applied by disabling toll roads or other expressway options, ensuring that the estimated travel distance more accurately reflects the everyday commuting conditions of employees who do not always rely on paid access routes. The output of this route calculation not only generates a visual path on the map but also provides the total travel distance. This distance then serves as the basis for carbon-emission calculations for commuting activities, enabling the system to establish a direct link between employee mobility and measurable reductions in the WFA model's carbon footprint.

2.3 Carbon savings

The carbon savings calculation in this study is based on actual travel distances obtained by integrating the Google Maps API. The calculation method involves subtracting the distance from an employee’s residence to the office from the distance between the employee’s residence and the WFA location used on a given day. The resulting difference, expressed in kilometers, serves as the basis for estimating emission savings. For the emission factor, this research refers to the study by Plötz et al. (2021), which reported an average emission of 149 g CO_2/km [5], as well as the findings of Xie and Lin (2025), who identified 146 g CO_2/km for gasoline vehicles under uniform speed conditions [6]. Considering both studies, an average coefficient of 147.5 g CO_2/km is adopted for the calculating vehicle-related carbon saving, complemented by an additional emission factor of 144 g CO_2/kmh to account for conditions of traffic congestion or vehicle idling [6]. For walking, the value is 55 g CO_2/km, and for cycling, it is 35 g CO_2/km, as reported by Fabien (2022) [7]. Accordingly, the simplified calculation can be expressed by the following equation :

$$Carbon\ Savings = (OD - WD)\ km \times 147.5\ g\ CO_2/km - 144\ g\ CO_2/kmh \quad (1)$$

$$Carbon\ Savings = Total\ Working\ Carbon - WD\ km \times 55\ g\ CO_2/km \quad (2)$$

$$Carbon\ Savings = Total\ Working\ Carbon - WD\ km \times 35\ g\ CO_2/km \quad (3)$$

From Equation (1), it can be observed that the calculation for vehicles is based on the commuting distance from home to office (OD), reduced by the distance from home to the WFA location (WD), and further adjusted by subtracting the hourly emissions generated during traffic congestion. Equations (2) and (3) represent the carbon emission calculations for walking and cycling, respectively. In this formulation, the total commuting emissions to the office are reduced by the distance from the WFA location. If the result is positive, it represents the corresponding carbon savings.

The result of this computation represents the amount of carbon an employee saves on a specific day by working from an alternative location rather than commuting to the central office. These carbon savings values can then be aggregated daily, weekly, or monthly to provide a comprehensive overview of WFA’s tangible contribution to emissions reduction. Subsequently, the calculated data are converted into a unique code in the form of a digital stamp, serving both as an identifier and verifiable evidence of environmentally friendly contributions within the geolocation-based WFA framework.

2.4 Unique stamp

The unique stamp generated in this study functions as a digital identity that integrates multiple key data elements related to WFA activities. The information embedded in the stamp includes geolocation data, employee identification, the date of the WFA activity, and the calculated carbon savings based on the commuting distance avoided. The process is shown on Figure 2.

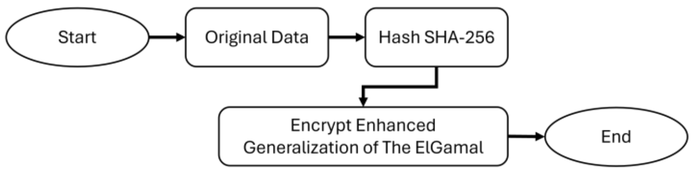

Fig. 2. Unique stamp creation process.

All data is processed using the cryptographic algorithm SHA-256 to generate a unique hash code with the JavaScript function `sha256(data)`. Once the employee's name, geolocation data, WFA date, and calculated carbon savings are hashed using SHA-256, the next stage involves encryption using the optimized ElGamal algorithm. The optimization applied to ElGamal ensures not only strong encryption but also improved computational efficiency compared to its conventional implementation, called the Generalization of the ElGamal [10].

Each key generated by the ElGamal algorithm incorporates a random number, thereby increasing the uniqueness of the resulting digital stamp. This mechanism guarantees that even when identical input data is processed, the resulting ciphertext remains distinct because randomness is used in the key generation process. Consequently, randomness not only strengthens security but also preserves the encryption scheme's non-deterministic property. For every variable involved in the ElGamal algorithm, both the public key and the private key are formally defined through the following equations (4) to (9).

$$p = Random\ Prime\ Number,\ 256 < p < 1000) \quad (4)$$

$$g = Primitive\ Root\ of\ p,\ g > p \quad (5)$$

$$x = Random\ Number,\ x < p - 2 \quad (6)$$

$$a = g^x mod\ p \quad (7)$$

$$y = Random\ Number,\ 2 \leq y < p - 2 \quad (8)$$

$$i = Random\ Number,\ 1 < iy < p - 1 \quad (9)$$

This study enhances the Generalization of the ElGamal algorithm by applying a block-based scheme that supports both hexadecimal and decimal computations. In this approach, the SHA-256-encrypted output is split into two hexadecimal blocks, which are then converted to decimal values for further processing.

In the process of enhancing the Generalization of the ElGamal algorithm, the encryption stage begins by converting the received message from hexadecimal to decimal. Each pair of hexadecimal characters, such as 4F or A2, is directly transformed into its decimal equivalent without first being converted into ASCII. The objective of this transformation is to simplify the encryption process by eliminating dependency on character representation and operating directly on numeric values. For example, if the initial message is 4FA2, then 4F is converted into 79 and A2 into 162, resulting in a decimal sequence of 79 and 162.

In the subsequent stage, each of these decimal values is encrypted using the generalized ElGamal algorithm. In the proposed method, each decimal value is treated as a plaintext number and encrypted into a ciphertext pair (c1, c2) via exponential and modular operations using the public key and a random number. This procedure ensures that every decimal value has a unique, secure, encrypted representation. Upon completion, the encryption process produces ciphertext in the form of a sequence of (c1, c2) pairs corresponding to each decimal value of the original message.

The final output of this process is an encrypted stamp unique to each WFA activity. Consequently, every stamp serves as secure, verifiable, and tamper-proof digital evidence of an employee's contribution to reducing carbon emissions.

3 Results and discussion

3.1 The Geolocation apps

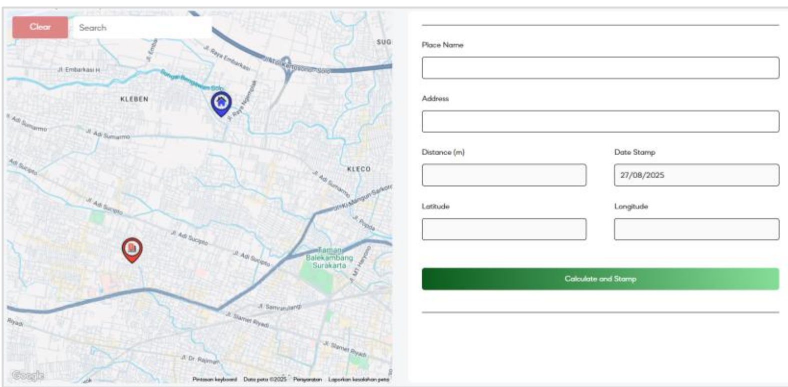

Fig. 3. Geolocation framework.

As illustrated in Figure 3, the left panel displays the Google Maps interface used to represent predefined key locations, namely the employee's residence and the company's central office. These two markers serve as reference points for calculating distance, determining routes, and estimating the potential carbon emissions saved when employees engage in WFA activities. The map interface is interactive, allowing users to easily view the geographic positions of each marker and the possible routes between home and office. For example, the distance shown in Figure 3 between the residence and the office is approximately ±4.1 km, which is used as the basis for estimating carbon savings.

Meanwhile, the right panel of the figure displays the information fields that automatically receive geolocation data from the Google Maps API. These fields include the place name, address, distance, latitude, and longitude, which specifically represent the selected WFA destination point. Through this integration, the system can store detailed information in a structured format, enabling further processing for distance calculation, carbon savings estimation, and the generation of a unique digital stamp.

The automation of this process is shown in Figure 4, where geolocation data obtained from the Google Maps API is directly entered into the available information fields. Once the markers for the employee's residence, the office, and the WFA location are defined, the system automatically displays the travel route along with detailed information in the fields, eliminating the need for manual input.

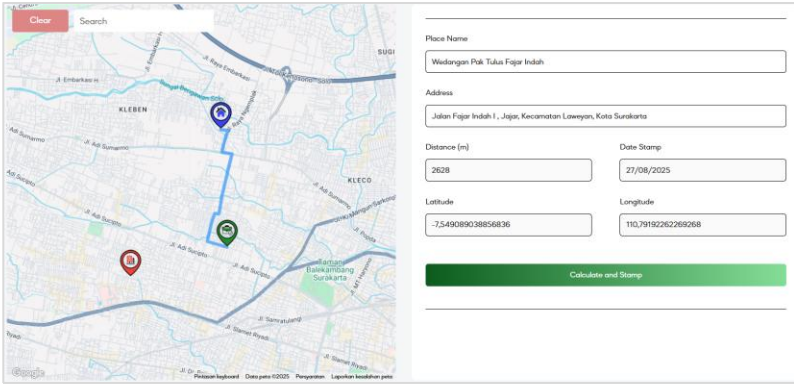

Fig. 4. Automatic route and field data capture.

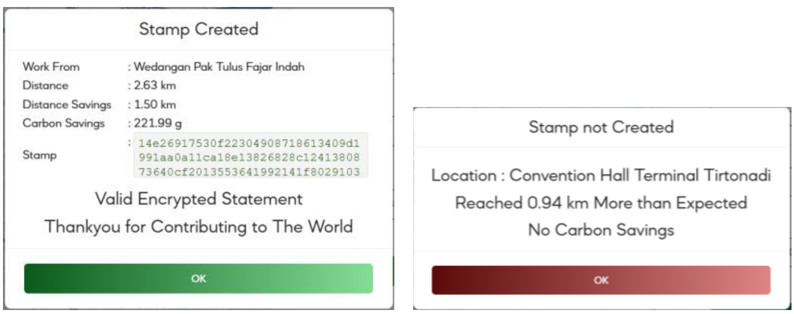

Fig. 5. The stamp.

A stamp can only be generated successfully if the selected WFA location is within the central office's service area. This condition is illustrated in the left panel of Figure 5, where the system automatically validates the location and permits stamp generation if the distance criterion is satisfied. Conversely, if the WFA location is farther from the office than the office location, the system displays a warning message, as shown in the right panel of the figure. This mechanism ensures that the stamp generation process remains consistent with the principle of carbon savings calculation based on actual travel distance.

3.2 The Unique Stamp algorithm

As described in Section 2.4, the primary data used in the stamp generation process include the employee's name, geolocation data, WFA date, and calculated carbon savings. These data elements were selected because they can represent the unique identity of each WFA activity while also serving as the foundation for quantifying the associated environmental impact. Once collected, all data are processed using the SHA-256 algorithm to produce a unique, permanent hash that cannot be altered without detection, thereby preserving data integrity.

The next stage involves encryption using the generalization of the ElGamal algorithm, which enhances the security of the previously generated hash. Through this encryption, the resulting digital stamp becomes not only unique but also secure for deployment within the geolocation-based work system. The results of data processing and stamp encryption are presented in Table 1, which illustrates the relationship between the input data and the final output, an encrypted digital identity.

Table 1. Encrypted process unique stamp.

<table>
<tr><th>No</th><th>Original Data</th><th>SHA-256 (Hash)</th><th>Enhanced Generalization of The ElGamal (Unique Stamp)</th></tr>
<tr><td>1</td><td>Bagas Dwi Yulianto|Wedangan Pak Tulus Fajar Indah|-7.549135/110.7919063|1506/222.13|Mon Aug 11 2025 07:35:50 GMT+0700 (Western Indonesia Time)</td><td>a2b29c37a575a593ef7b599bf60c8a5633c94c87a27d884603b1f8a1673dada0</td><td>07717423b0d42682a11d200b01a05e10201104c3df1571cc2863651b62ab1922a115e1630462640fb3cd29c0223cd28f2b12071280bb0cd23128c03e02525d4031b93082ab04d07727b3cc38821e3c92b53e83ef1c22961491733f81910633b3</td></tr>
<tr><td>2</td><td>Bagas Dwi Yulianto|SFA Steak & Resto Klodran|-7.5351372/110.7921524|3456/509.76|Tue Aug 12 2025 07:59:03 GMT+0700 (Western Indonesia Time)</td><td>115779ad6777d9720688c3061120e1bc817127ef272da6ceec8848b9319416be</td><td>07e1393a92ba33d24740126f2930d702e3480081870523d41000bd1491951850ac0952a11ba03231611500511535a32c20733e3c31f04012cd30e2fe0990c30343f119f0a51ba29b3c20ed2452a92fb00629c21109e1790f30b51882132d42ff</td></tr>
<tr><td>3</td><td>Imanuel Zega|Kopi Kulo|-7.551867700000001/110.7732192|589/86.88|Tue Aug 12 2025 07:17:47 GMT+0700 (Western Indonesia Time)</td><td>dbff02022d1be54e2563bfa0d5c5d9889ab4c47024439aa499e27f6762f27a2a</td><td>05b0282a018b20e16217e3d834233940225400906d15107817b0a31b83013103720581a21da3082d028011c0483f71d32b804307c09c15b1811d62db2c705310c1f835a2912e90f919e2a310810732c3670463c507a2ba1f14050170321ac361</td></tr>
<tr><td>4</td><td>Imanuel Zega|Edupark|-7.546090422765574/110.77068739814074|55/8.11|Wed Aug 13 2025 07:22:57 GMT+0700 (Western Indonesia Time)</td><td>60538288ab1f652fe251571a7fd5000d00f7110465e8415f3d97856bca10af24</td><td>3363bc22226c03c39e3d005937732106e1ee2101772a304e23d2b92c904c0ce3a50913542be1923b840311700032c2ac3480000c23ba3d420b3f73e317709423d2261190753543b83ca11b11008510f2730902210642d619b0f525915d23d09d</td></tr>
<tr><td>5</td><td>Wisnu Wendanto|Swiss-Belhotel Solo|-7.553333100000001/110.8222099|5740/846.65|Thu Aug 14 2025 07:55:17 GMT+0700 (Western Indonesia Time)</td><td>061178570403c0a3450a075ebef39b8f29dd78b30cfaa2c6929e2ba45867881d</td><td>3ef3c719125712e2f40793031ff10333216626c2650b72b92a61231cd2f116f29e2cb3b60803352000922d01c900437f3a11f240213c3a403530a19e29a2c60fb2bc16e0072de08b0791b22d81d614d0b726b2e10222901e527a0b620c277379</td></tr>
<tr><td>6</td><td>Wisnu Wendanto|Swiss-Belinn Saripetojo Solo|-7.5626526/110.7953045|1724/254.29|Fri Aug 15 2025 07:56:24 GMT+0700 (Western Indonesia Time)</td><td>520e4d62906d9136bca4b783eeee0d1db5771d198c747ed3ad5024da608a66f7</td><td>1a70370413731ee21711001002507d1880960381c706911324529c2671e52f229517f35728f0192af2a83a63f10e30622291990313613bc25308227d3d12190ca3421fa00a03c3aa1572aa3c30884022eb3d111f32a35002433311501f22421e</td></tr>
<tr><td>7</td><td>Bagas Dwi Yulianto|Mie Cinta Rasa|-7.528395084880524/110.79387984655675|3530/588.51|Mon Sep 15 2025 07:55:50 GMT+0700 (Western Indonesia Time)</td><td>26de84dbce8ab189a46f1cf16cdffd8b133c468dd4d1cc7806c4cec2bb491a8b</td><td>11c13b0d117533932a1652943563b90131561a70e00ca23b1230372441d80a31e216038604028522c21130b2350ad29125a0462782ff2322af2dc3ee3f206b2cc38d31a0292e331113717029326a0d508125701b2293850d529019b08529526c</td></tr>
<tr><td>8</td><td>Wisnu Wendanto|KO-KOK|-7,5472246679883295/110,83136971657517|7452</td><td>1d8675e245fac110bb40ce834bda8b159d7779a5ed9e7aa13a492928a46154bc</td><td>0771a11482ca14c0ad3813433d51b00c70c52c63a20bc2803c236a2270d52022ff3ae25d1e50fd2d00f30822b623108e16b01c3531b30723ab18d2bd2</td></tr>
</table>

 https://doi.org/10.1051/e3sconf/202668701014

No	Original Data	SHA-256 (Hash)	Enhanced Generalization of The ElGamal (Unique Stamp)
	/1263.98|Mon Sep 15 2025 07:46:54 GMT+0700 (Western Indonesia Time)		be145136369176393001 0a11223a91b619704c1a210c0f21892763c335d0dd0ef34823f
9	Imanuel Zega|UPITRA Campus|-7,553728844411947/110,77722980216599|0/75.94|Mon Sep 15 2025 07:16:08 GMT+0700 (Western Indonesia Time)	1f25c2cc1ba59d1c9d830a07e35d3e912924c8926dcf7be6487106cecef4d951	2e936028231433338b1d43fe3762e340a3ab07d0a33e33d826d38f01a3730b229d27d24012416c1e51b31d517638124608f2fd13e2f12a40772d91d90f71173421c81073753300802631080c439c1e31982c70cf12d05439d3191d424c0900a9
10	Imanuel Zega|Mie Oilin|-7.550346278465356/110.77024310635555|371/96.35|Wed Sep 18 2025 07:37:03 GMT+0700 (Western Indonesia Time)	248a217b59560de0517f0e82f2d31002dff4c315b9204e8193e859adf7837d76	17339510c1691061620fb2a238a01f02c3792de1f422701c4070340850c40190253d215e12d29905d17f1333972e91782cb3803b837039c2ed0460b81e627d1923523f61f71f21980d43961e21d305d1c93a614f21126011a0be10c0c7124067

As shown in Table 1, private data in this study are used as input to generate unique digital stamps, assigning each employee a distinct code for every WFA activity. This ensures no two stamps are identical, preserving data integrity and authenticity. Each stamp is valid only for a specific parameter set, preventing replication without re-encryption. The algorithm's evaluation focused on security and encryption efficiency, particularly on ciphertext expansion, the difference between encrypted and original data sizes. Greater expansion indicates stronger confidentiality protection, as sensitive information becomes harder to infer or reconstruct, enhancing the robustness and reliability of the encryption outcome [11]. In addition to ciphertext expansion, the evaluation also includes calculating the Avalanche Effect, which is compared with the ciphertext results for the proposed method. The corresponding computation is presented in equation (10). This test provides insights into the extent of changes produced in the ciphertext when minimal variations occur in the input, thereby strengthening the assessment of the encryption scheme's reliability [12].

$$Avalanche\ Effect\ (\%) = \frac{Sum\ of\ Different\ Ciphertext}{Amount\ of\ Ciphertext} \times 100\% \qquad (10)$$

Equation (10) the Avalanche Effect is measured as the percentage obtained by dividing the number of differing characters by the total number of characters in the ciphertext. The evaluation results are summarized in Table 2.

Table 2. Avalanche Effect.

No	Data	Avalanche Effect
1	Original ElGamal	64,84%
2	Generalization of The ElGamal	70.57%
3	Enhanced Generalization of The ElGamal	92.70%

Based on the evaluation results presented in Table 2, the avalanche effect was measured at 92.70%, indicating strong performance, as even minor changes in the input produced substantial variations in the ciphertext, thereby surpassing the predecessor algorithm's performance.

Table 3. Processing speed evaluation.

No	Algorithm	Encryption (s)	Decryption (s)
1	Original ElGamal	0,044595	0,022627
2	Generalization of The ElGamal	0,024604	0,019820
3	Enhanced Generalization of The ElGamal	0,016223	0,016270

From Table 3, the evaluation shows that the proposed method achieves the fastest encryption speed at 0.016223 seconds and the fastest decryption speed at 0.016270 seconds. This result demonstrates a significant performance improvement. A more detailed illustration is provided in Figure 6.

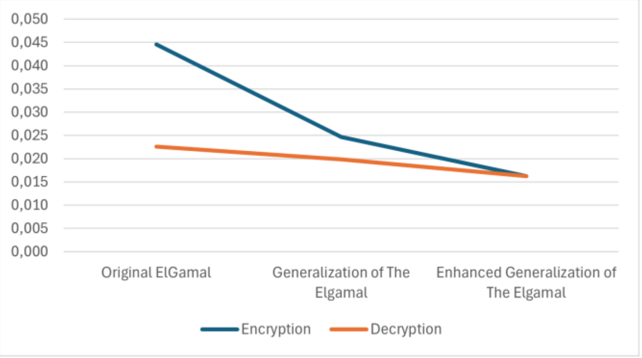

Fig. 6. Speed evaluation.

Table 4. Ciphertext expansion.

No	Algorithm	Data	Size (Kb)
1	Original ElGamal	32 hex to 384 hex	44,8
2	Generalization of The ElGamal	32 hex to 384 hex	44,9
3	Enhanced Generalization of The ElGamal	32 hex to 192 hex	22,4

From Table 4, it can be observed that the proposed method requires the smallest memory size, making it the most efficient in terms of server capacity savings, which is also linked to carbon reduction. A more detailed illustration is presented in Figure 7.

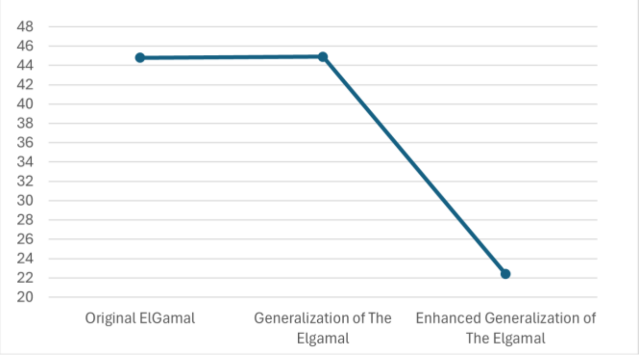

Fig. 7. Ciphertext expansion.

From the three evaluations, it can be concluded that the proposed method, namely the Enhanced Generalization of ElGamal, outperforms its predecessors, thereby ensuring that the generated unique stamp provides a high level of security integrity.

3.3 Carbon saving calculation

Table 5 presents the results of carbon savings calculations for each WFA activity performed by the employees, derived using equation (1) to (3). The calculated carbon savings vary depending on the actual distance between the employee's residence and the office. Employees residing farther from the office tend to generate greater potential reductions in carbon emissions when engaging in WFA activities. This finding highlights the significant role of geographical location in determining the extent of an employee's contribution to reducing the overall carbon footprint.

Table 5. Carbon savings calculation.

No	Data	Office Distance	WFA Distance	Carbon Savings	Mode
1	Bagas Dwi Yulianto (1)	4133 m	2627 m	222.13 g	Vehicle
2	Bagas Dwi Yulianto (2)	4133 m	677 m	509.76 g	Vehicle
3	Imanuel Zega (3)	821 m	232 m	86.88 g	Vehicle
4	Imanuel Zega (4)	821 m	766 m	8.11 g	Vehicle
5	Wisnu Wendanto (5)	8917 m	3177 m	846.65 g	Vehicle
6	Wisnu Wendanto (6)	8917 m	7193 m	254.29 g	Vehicle
7	Bagas Dwi Yulianto	4133 m	603 m	588.51 g	Cycling
8	Wisnu Wendanto (8)	8917 m	1465 m	1263.98 g	Cycling
9	Imanuel Zega (9)	821 m	821 m	75.94 g	Walking
10	Imanuel Zega (10)	821 m	450 m	86.88 g	Walking

4 Conclusion

The geolocation framework, up to the stage of digital stamp generation, has been successfully implemented as a Geolocation Application designed to manage employees' WFA activities. By combining the SHA-256 algorithm with the Enhanced Generalization of ElGamal, the system can generate unique digital stamps, ensuring that each WFA activity is securely recorded with a distinct digital identity. The encryption process produces a ciphertext that expands to up to 192 hexadecimal digits, thereby strengthening system resilience while maintaining a minimum data size of 22.4 KB, which contributes to storage efficiency. An avalanche effect of 92.70% demonstrates strong performance in preserving data integrity and security. Furthermore, the encryption and decryption speeds of 0.016223 seconds and 0.016270 seconds, respectively, highlight the efficiency of the proposed method. Across all three evaluations, the method achieved superior performance compared to its predecessors. In addition, carbon savings are accurately calculated using the Google Maps API, which measures commuting distances between employees' homes and offices. Results show that longer distances yield greater reductions in emissions through WFA adoption. Thus, the framework enhances data security while promoting environmental sustainability by minimizing the overall carbon footprint.

References

1. B. Barua, M.O. Islam, H. Kibria, R. Barua, Analysis of Creativity at The Workplace Through Employee Empowerment. International Journal of Organizational Analysis **33**, 2547–2572 (2024). https://doi.org/10.1108/IJOA-05-2024-4534
2. P. Choudhury, C. Foroughi, B. Larson, Work From Anywhere: The Productivity Effects of Geographic Flexibility. Strategic Management Journal **42**, 655–683 (2021). https://doi.org/10.1002/smj.3251
3. M.F. Asyrofi, I.G.D. Nugraha, Cybersecurity Of Work From Anywhere Model For Government : A Systematic Literature Review. International Journal of Electrical, Computer, Biomedical Engineering **3**, 117–141 (2025). https://doi.org/10.62146/ijecbe.v3i1.113
4. G. Santos, R. Azhari, Can We Save GHG Emissions by Working From Home?. Environmental Research Communications **4**, 035007 (2022). https://doi.org/10.1088/2515-7620/ac3d3e
5. P. Plötz, C. Moll, G. Bieker, P. Mock, From Lab-to-Road: Real-World Fuel Consumption and CO2 Emissions of Plug-In Hybrid Electric Vehicles. Environmental Research Letters **16**, (2021). https://doi.org/10.1088/1748-9326/abef8c
6. H. Xie, G. Lin, Calculation and Analysis of Carbon Emissions for Fuel Vehicles and Electric Vehicles. SAE Technical Paper. **2025-01-7096**. https://doi.org/10.4271/2025-01-7096
7. F. Leurent, From Food to Foot: The Energy and Carbon Flows of the Human Body at Walking and Cycling. Journal of Energy Power Technology **4**, (2022). https://doi.org/10.21926/jept.2203025
8. G. Al-Asad, M. Al-Husainy, M. Bani-Hani, A.E. Al-Zu’bi, S. Albatienh S, H. Abuoliem, Comparative Assessment of Hash Functions in Securing Encrypted Images. Engineering, Technolology & Applied Science Research **14**, 18750–18755 (2024). https://doi.org/10.48084/etasr.8961
9. A. Muñoz-Villamizar, E.L. Solano-Charris, M. AzadDisfany, L. Reyes-Rubiano, Study of Urban-Traffic Congestion Based on Google Maps API: The Case of Boston. IFAC-Pap. **54**, 211–216 (2021). https://doi.org/10.1016/j.ifacol.2021.08.079
10. I. Zega, B.D. Yulianto, Enhancing the Encryption Capabilities of the Generalization of the ElGamal Algorithm for Document Security. Journal of Applied Informatics and Computing **9**, 1266–1271 (2025). https://doi.org/10.30871/jaic.v9i4.9737
11. F. Thabit, S. Alhomdy, S. Jagtap, Security Analysis and Performance Evaluation of a New Lightweight Cryptographic Algorithm for Cloud Computing. Global Transition Proceedings **2**, 100–110 (2021). https://doi.org/10.1016/j.gltp.2021.01.014
12. R. Verma, A.K. Sharma, Cryptography: Avalanche effect of AES and RSA. International Journal of Science and Research Publications **10**, p10013 (2020). https://doi.org/10.29322/IJSRP.10.04.2020.p10013