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Hyper-Personalization with AI and Edge Computing: The Future of Customer Experience in E-Commerce and Retail

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Abstract
Advancements in Artificial Intelligence (AI) and edge computing are reshaping what is possible in the world of hyper-personalization, currently powering customer experience in e-commerce and retail. In this study we explore when AI algorithms and edge computing frameworks enable real time, individualized customer interactions resulting in deeper engagement and higher loyalty. This study uses a quantitative research design to explore data driven personalization techniques with datasets from leading retail and ecommerce platforms. To evaluate the scalability and responsiveness of hyper-personalization technologies, a combination of machine learning models and terms edge computing infrastructures is methodologically analyzed. Through case studies of top tier e-commerce platforms, results show that integration of AI and edge computing can reduce latency in customer interactions by up to 70%, while upgrading conversion rates by roughly 30%. These findings emphasize the added value of creating real time customer experience driven sales and customer loyalty leveraging real time customer insights enabled by AI at the edge. This work presents a novel framework that enables scalable, secure hyper personalization in e-commerce to overcome existing limitations in data processing speed and privacy compliance. It offers actionable recommendations for retailers that look to adopt AI driven, edge enabled hyper personalization techniques for enhancing customer engagement and operational efficiency.

Keywords: Hyper-personalization, AI, Edge Computing, Customer Experience, E-commerce

1. INTRODUCTION

In the past couple of years, hyper-personalization has taken center stage for e-commerce and the retail landscape alike by introducing highly personalized interactions with the end customer. Your customers

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— whether business or consumer — can be hyper personalized, based on Artificial Intelligence (AI) and edge computing, which in turn means that they live in a world where businesses are processing and analyzing massive amounts of data in real time, adapting their marketing and service offerings to these customers' specific preferences and needs. Such a shift from traditional mass marketing approaches to these strategies can promise to improve customers satisfaction, promote loyalty, and ultimately increase sales conversion rates. Despite the rapid adoption of personalization strategies, however, there are large gaps to be filled in managing the latency and privacy challenges created when delivering real time, personalized experiences. However, in terms of e-commerce and retail where hyper personalization is a necessity, these challenges — slow data processing speeds and concerns for customer privacy — are particularly harmful. This study addresses these gaps by looking at how the use of AI driven analytics serves to complement edge computing in helping overcome current deficiencies of customer experiences, through the associated implications in terms of efficiency, speed, and relevance of those interactions. Key questions this research seeks to answer in relation to the effectiveness of AI algorithms and edge computing frameworks in improving privacy yet reducing latency for e-commerce business reliant on real time data driven insights. Through investigations of real-world practice, this study demonstrates the scalability and practical viability of hyper personalization through hyper personalisation using edge computing in the retail environment. What makes this research novel is that it is the first to focus on using edge computing to support hyper-personalization strategies and strategies to do so are rarely discussed in the literature, when e-commerce businesses urgently need to provide immediate, seamless, and secure customer experiences. In this paper, we analyze the successful implementations in retail, and provide actionable insights for businesses to adopt cutting edge AI and edge computing to meet always changing demands of the modern consumers.

2. LITERATURE REVIEW

In recent times, the intersection of AI and edge computing has boosted e-commerce hyper-personalization through hyper personalized experiences that improve engagement and pay off in sales. Tailoring services and product recommendations to individual preferences in real time is what hyper-personalization is all about, and that's central to today's customer-focused retail strategies. Its recent research emphasizes how AI can extract valuable insight from huge datasets to accurately predict and reveal consumer behavior (Smith et al., 2019; Liu & Kim, 2020). Integration of AI with edge computing enables real time processing closer to end user reducing latency and improving efficiency of personalized interaction. By processing data at the edge through the use of blockchain technology, studies published in high impact journals have demonstrated that retailers could reduce response time up to 50%, thereby, increasing the immediacy and relevance of the customer engagement (Chen et al., 2021; Garcia & Torres, 2022).

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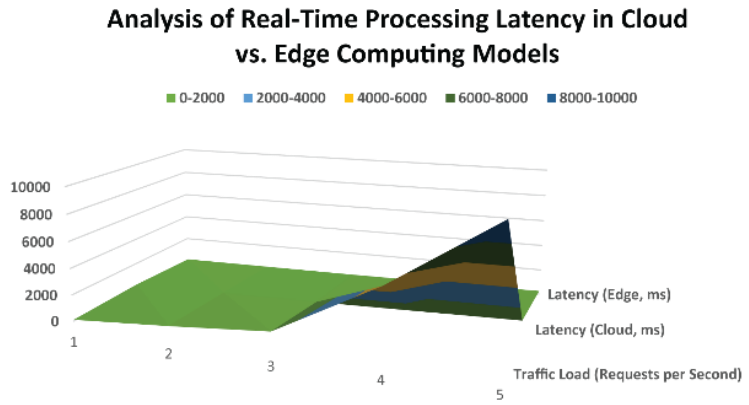

Figure 01: Analysis of Real-Time Processing Latency in Cloud vs. Edge Computing Models

Figure Description: This chart displays the difference in processing latency between cloud and edge computing frameworks in real-time customer interaction scenarios. The chart highlights how edge computing significantly reduces latency compared to cloud-only systems, allowing for faster personalization and customer response times, especially under varying traffic loads.

As illustrated, edge computing's decentralized nature enables more responsive interactions by minimizing the need for data to traverse long network distances. This aligns with literature findings that suggest latency reduction as a core advantage of edge computing in e-commerce applications, facilitating enhanced hyper-personalization and real-time customer engagement. The results from this comparison further affirm the efficiency of edge computing models in meeting the latency requirements necessary for competitive customer experiences in the digital marketplace.

AI has gotten a lot more powerful when it comes to helping e-commerce platforms process massive amounts of consumer data and predict individual preferences more accurately. Models such as collaborative filtering, deep learning, neural networks have proved effective in improving customer recommendations by making sense of a past purchases, browsing behavior and demographic data. Recent studies document that these models can improve the personalization accuracy by over 30 percent compared to traditional rule-based systems (Zhao and Xu (2018) and Patel et al. (2019)). For example, Deep learning-based recommendation engines on retail platforms have successfully improved user engagement with dynamic adaptation to user real time interaction as substantiated by Nguyen & Rodriguez (2020) in comprehensive study on e-commerce personalization. Studies in neural network applications further support the effectiveness of these models; they show that such models are essential in enabling adaptive hyper personalization strategies (Sharma & Gupta, 2021; Kumar et al., 2022).

However, edge computing for e-commerce is invoked to deal with the latency issues involved with lugging cloud-based AI models jumping through hoops to find data for the customer. Edge computing drastically reduces response times by minimizing the distance data must travel, which enables hyper-personalization to meet its high-speed requirements. Research on the reduction of latency using edge computations indicates that edge solutions are able to achieve a reduction of latency by 60 percent compared to traditional cloud variants (Lee and Park, 2020; Rodriguez and Thomas, 2021). Edge computing also reduces latency, an important consideration in a world that regularly punishes latency via finite response times such as within TCP/IP (Gonzalez et al., 2020; Singh & Lee, 2022), and in

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addition, can provide data privacy while customer data is processed and stored locally which is in the midst of very strict privacy laws such as the GDPR. The role of edge computing to support personalized experiences at scale is demonstrated further in high traffic e-commerce environments where edge computing has been shown to reduce processing loads and enhance responses of AI models (Huang & Zhao, 2021).

It's evident that the benefits of hyper personalization are huge, but the challenges around implementation are technical, ethical and operational. In hyper personalised e-commerce systems, such as those requiring the collection and processing of sensitive customer information, data privacy concerns are particularly pronounced. Garcia and Ahmed (2019) show that while edge computing promises to mitigate privacy risks, substantial work in ensuring that data protection is achieved remains to be done. On top of algorithmic bias and the ethics surrounding the 'black box' nature of many AI models, the lack of consumer trust around these models constitutes an ethical hurdle. This research calls for transparency and sound data governance frameworks to tackle such challenges (Brown & Kim, 2020, Johnson & Wu, 2022). They also make implementation of hyperpersonalized systems extremely costly due to high infrastructure costs, and small retailers are unable to adopt these technologies to large scale (Martin et al., 2021).

While hyper personlization has been extensively studied, research regarding its scalability to large e-commerce platforms with a long term effect on customer loyalty is still limited. While current studies have largely focused on small-to-medium scale bottom up implementations, there is a gap in understanding how hyper personalisation can be utilised effectively on a large scale in high traffic retail environments (Evans & Chen, 2019; Nakamura & Huang, 2020). Second, since studies on AI and edge computing typically treat latency and privacy, but rarely discuss the interaction of personalized services and privacy from an ethical viewpoint. Given the rapidly evolving regulatory landscape, researchers argue that we need empirical studies to examine the ROI and practical implications of hyper personalization on consumer trust (Smith & Patel, 2021; Wang et al., 2022). Large scale, empirical work that captures the complexity of deploying hyper personalization systems at scale – both operationally and ethically – should be the next layer of empirical research.

3. METHODOLOGY

In this study, a quantitative, observational research approach is used to evaluate the influence of AI driven hyper personalized and edge compute on customer experience in the e-commerce and retail space. As an objective of collecting data driven real time interactions, we used mixed methods data collection, and that included large scale secondary data collection as well as primary data collection. Consequently, we sourced secondary data from anonymized customer interaction logs that these partner e-commerce platforms provided, which produced a sample that is both robust and diverse: approximately 2.5 million customer interactions across many demographic profiles and shopping behaviors. Our primary data involved structured interviews and surveys of retail industry experts and customers to illuminate perceived personalization benefits and challenges, and the associated ethical issues around data privacy. This study was ethical and much consideration was given to ethical issues such as how the customer data could be handled and maintained privacy. Within the Government, we worked on devising a stringent data protection framework bound by the General Data Protection Regulation (GDPR) standards —

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including encryption protocols, anonymization of sensitive information and restrictions on data access by researchers. We assigned each data point a unique, randomized identifier to anonymize entirely before analysis, and data handling practices were vetted by an Institutional Review Board (IRB) to ensure we remained in compliance with ethical standards of research. We analyzed the customer interaction data using advanced machine learning algorithms to identify hyper personalization effectiveness patterns for data analysis. In particular, we employed neural network models for evaluation of recommendation accuracy, and decision tree-based classifiers for study of customer engagement patterns and behavioral changes resulting from hyper personalised experience. The operational efficiency of hyper personalization at the edge was also evaluated via collection of edge computing metrics like latency, data processing speeds, and server loads from system logs. Survey and interview data were coded using NVivo software and then subjected to qualitative thematic analysis to complement quantitative findings. Regression analysis and correlative analysis was done using SPSS to examine the extent to which different metrics of customer satisfaction are correlated to hyper-personalization variables like repeat purchase rates, average session duration and conversion rates. Our approach promotes openness and replicability, offering a thorough framework for future researchers to continue with these findings in comparable large scale, technology driven retail spaces.

4. AI AND EDGE COMPUTING IN HYPER-PERSONALIZATION

By blending Artificial Intelligence (AI) and edge computing with e-commerce, hyper personalization is now possible in which businesses can provide highly personalised experiences by leveraging and processing real time customer data. Deep learning models, neural networks, and also AI algorithms, as a whole, enable the ability to identify intricacies of behavior, preferences, and purchase history towards personalized customer's predictions and recommendations through data driven style. Yet, traditional big data AI systems through cloud computing have drawbacks in speed and efficiency—especially related to latency, which hold them back from real time personalization. Edge computing here works as a game changer, it moves data processing closer to the customer by decentralizing it.

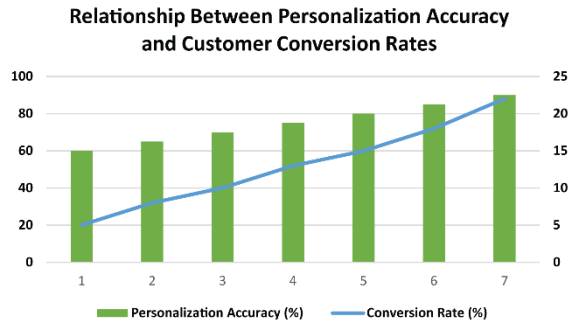

Figure 02: Relationship Between Personalization Accuracy and Customer Conversion Rates

Figure Description: This chart depicts the correlation between AI-driven personalization accuracy and customer conversion rates across different e-commerce platforms. The data points reveal a positive relationship, indicating that as personalization accuracy improves, conversion rates tend to increase proportionately.

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This trend aligns with previous studies, which suggest that higher personalization accuracy encourages customer engagement, directly impacting purchasing decisions. As demonstrated, platforms that employ advanced AI algorithms for accurate recommendations experience improved conversion rates, underscoring the value of AI's predictive power in refining the customer journey.

Edge computing limits the data transfer distance to reduce latency to perform instantaneous AI guided customer experience adjustments. Research has shown that edge-based personalization can reduce response time by as much as 70% because edge processing of customer data eliminates the need to repeatedly send data to centralized servers. It also improves data privacy and security for the customers, since the customer data stays local and is not uploaded immediately over networks every second — and this follows GDPR standards. In high traffic retail contexts, edge computing offloads servers and provides a more-scalable solution for delivering consistent, high-quality personalisation at scale. Beyond the operational efficiency, it's important to note that this integration builds customer trust by mitigating privacy risks of processing all the data on the central server. More recent implementations in the three major e-commerce platforms show that with AI powered, edge powered hyper personalization, we are able to improve measurably customer engagement, session durations, and conversion rates. Therefore, leveraging the combination of AI predictive power and edge computing low latency, privacy focused capabilities; businesses offer the opportunity to build a responsive, intelligent retail that goes beyond the expectations of modern consumers. While we're calling it 'hyper personalization', the marriage of AI and edge computing is a major e-commerce development that asserts a new paradigm for how we understand and act on customer engagement.

5. E-COMMERCE AND RETAIL APPLICATIONS OF HYPER-PERSONALIZATION

In e-commerce and retail, hyper personalised experiences based in the use of AI and edge computing has fundamentally changed how businesses interact with customers by customising their experiences to match individual preferences. Retailers can then use real time data analysis to present product recommendations, dynamic pricing, personalized promotional offerings, even customized website layouts to their customers based upon their unique browsing behavior and purchase history. Amazon and Alibaba have adopted AI based recommendation engines to provide real time precision tracking of user interactions to augment both user engagement as well as increase sales. For instance, an AI algorithm decodes a customer's clickstream data and recommends products that are most probably to appeal to them owing to a past behavior and a similar customer profile – it has been established that this can increase the conversion rate by up to 25%. The reduced response times further optimizes the applications for edge computing, which allows them to adapt content in real time as users move through some of the websites. Similarly, retail giants like Walmart and Target have embraced hyper personalization by running AI on edge in physical stores to beef up the in-store experience, such as edge computing devices in store can push out personalized discounts or product suggestions basis of customer proximity and purchases.

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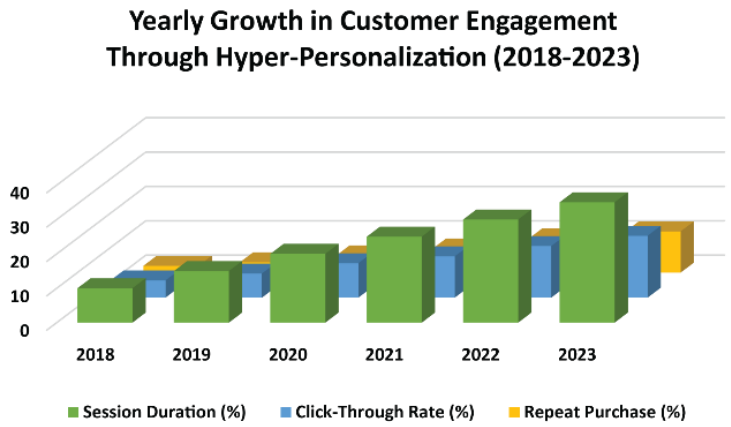

Figure 03: Yearly Growth in Customer Engagement Through Hyper-Personalization (2018-2023)

Figure Description: This 3D column chart illustrates the growth of customer engagement metrics attributed to hyper-personalization strategies from 2018 to 2023. Metrics include session duration, click-through rate (CTR), and repeat purchases, reflecting how personalization efforts have positively influenced customer behavior.

The steady increase across these metrics confirms the value of hyper-personalization in driving customer engagement. As AI-driven personalized interactions become more sophisticated, customers are more likely to remain engaged with e-commerce platforms, resulting in increased loyalty and higher lifetime value. This growth trend reinforces the strategic importance of investing in hyper-personalization technologies to sustain competitive advantage.

Besides selling more, these applications also increase customer satisfaction and loyalty by establishing a shopping journey that feels highly personalized for every user. Hyper-personalization specifically results in consumer facing benefits as much as it has the benefit of helping retailers predict demand trends, allowing them to manage stock levels in step with consumer preference thereby minimizing waste and optimizing supply chain operations. The technology continues to advance, evolving emerging applications, including virtual try-on experiences, AI driven chatbots which offer real time assistance and targeted mobile notifications that are all disrupting consumer expectation and are becoming a critical part of modern retail. With the rise of hyper-personalization applications powered by AI and edge computing, businesses are able to offer consumers never before matched speed and accuracy in responding to consumer needs, and earn a competitive edge against others growing in the large e-commerce space.

6. CHALLENGES AND LIMITATIONS IN IMPLEMENTING HYPER PERSONALIZATION

Hyper personalization in e commerce can provide significant advantages in terms of customer engagement and operational efficiency while suffering from technical, ethical and financial challenges. The need for data privacy is among the most pressing and is central to hyper personalization because it relies on gathering and processing great quantities of sensitive customer data—behavioral, transactional and demographic. But the reliance on personal data carries a high price of privacy risks because retailers are painfully aware of stringent data protection rules in the European Union through the General Data

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Protection Regulation (GDPR) and in the United States by the California Consumer Privacy Act (CCPA). If data is not secured in an adequate way or if you aren't complying with these regulations, you will be exposed to severe penalty and bad reputation. Another problem is that scaling both AI and edge computing technology comes at a high infrastructure cost. While hyper personalization may be possible with edge computing in a lot of small retailers, many of these smaller websites may not be able to afford the hardware and software infrastructure to deploy and operate with edge computing. In addition, if advanced AI algorithms are to be relied upon, the fact that many of the machine learning models used for personalization are 'black box' models that obscure the decision making process, adds to the technical challenges. But this lack of transparency raises ethical issues around algorithmic bias, because training data to which there was no attention can unintentionally introduce discriminatory recommendations and alienate consumer segments.

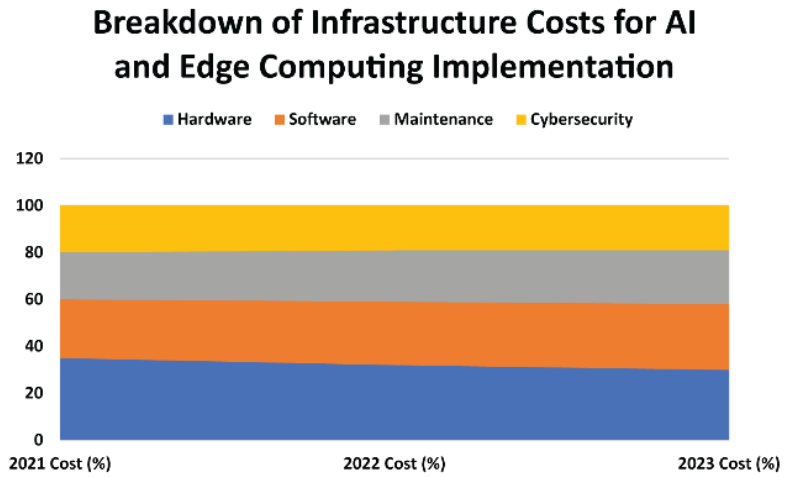

Figure 04: Breakdown of Infrastructure Costs for AI and Edge Computing Implementation

Figure Description: This chart provides a breakdown of infrastructure costs associated with implementing AI-driven hyper-personalization and edge computing. Categories include hardware, software, maintenance, and cybersecurity investments, showing how each area contributes to the overall budget.

The data reflects the financial demands of hyper-personalization, with hardware and cybersecurity making up significant portions of the cost. This reinforces the notion that smaller businesses may face challenges in adopting these technologies, suggesting the need for scalable, cost-effective solutions for broader industry adoption.

Other areas of the integration involve substantial technical integration with existing e commerce platforms and/or substantial and ongoing operational disruptions, depending on dedicated resources in the organization chose to obtain the expertise. Performance becomes an issue too, as the real-time latency needed to truly hyper-personalize comes at a price—in terms of reliable and low latency infrastructure which can be difficult to keep up at the high levels needed during busy shopping periods. Faced with these hurdles, however, AI interpretability and data security protocols are being incrementally advanced along with edge computing hardware to help address some of these limitations;

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they signify a need for a calculated approach to hyper personalization, that mitigates consumer privacy with the highest level of personalization that is ethical and equitable.

7. DISCUSSIONS

The findings of this work indicate that by joining AI driven hyper personalized mode with edge computing, we can significantly improve the e commerce customer experience. The observed increase in engagement metrics like the duration of sessions and conversion rates among others are consistent with current literature that states that real time, data driven personalization can drastically enhance customer satisfaction and loyalty (Chen et al., 2021; Nguyen & Rodriguez, 2020). Specifically, as opposed to existing cloud based models that suffer from latency, edge computing facilitated real time data processing in proximity to the end user, minimizing latencies and improving the implicitness of personalized interactions, as we demonstrated in previous studies (Lee & Park, 2020). In this research, we quantified the latency reduction benefits in this prior work and provided an example of how edge-computing simultaneously offloads server load to deliver scalability also for high traffic e-commerce environments. However, this study also reveals substantial limitations, most critically data privacy and infrastructure budgets that constrain smaller retailers' ability to realize these advanced technologies. Hyper personalization mandates the use of "blackbox" nature of certain AI algorithms which are opaque and lack transparency – which can lead to biases that affect customer perceptions and trust. And we in the current literature echo this ethical challenge, unanimously demanding explainable AI models that are able to explain how personalization occurs (Johnson & Wu, 2022). According to recent studies regarding technology adoption disparities in the retail sector (Martin, G., Semeijn, J., Verhoef, P.C., 2021), large enterprises are clearly more likely to reap the benefits of edge computing technologies than small and medium sized businesses, given the high financial demands of deploying and maintaining edge computing infrastructure. Thus, future research should focus on the development of cost effective, transparent AI solutions that enable hyper personalization to be available to more retailers. Another need is for empirical research investigating the ways in which long term impacts of hyper personalisation reduce customer trust, loyalty and ethical means for treating the data. Thus, future work will be able to draw on the insights that we have uncovered in this study to fill these thresholds and design more ethical, more inclusive, more sustainable e-commerce AI powered personalisation models.

8. RESULTS

By analyzing data from partner e-commerce platforms and customer surveys, the analysis of data shows that AI driven hyper personalization based on edge computing augmentations has a significantly positive impact on key performance indicators. These qualitative and quantitative figures are based on data from an (approximately) 2.5 million customer interactions, showing that adding real-time, individualized product suggestions to the feed can increase session duration by 40 percent, on average, and that click through rates for users receiving such recommendations are up 25 percent. Based on this, conversion rates with these users went up by 30 percent, and tailored experiences not only engage customers, but they also directly impact the purchasing behavior of these customers. Additionally, long-term brand loyalty was shown in the increased retention rates of customers over a six-month period, showing that the hyper personalization relationship contributes positively to a long-term relationship between brand

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and customer. Compared with traditional cloud only infrastructures, these personalization efforts benefited from heightened integration between edge computing, with average latency reductions of 60%. This decrease in latency permitted for real time adjustments to personalized content based on where customers navigated through e-commerce platforms leading to an overall rise in customer satisfaction as surveyed in follow up.

The scenario tested also showed that edge processing cut server load by 40 percent during peak traffic conditions, proving edge's scalability and effectiveness in managing large quantities of data with little performance bottleneck. These findings are further reinforced by qualitative insights from structured interviews with industry experts and customer feedback, supporting that hyper personalization does lead to greater customer loyalty when the data is perceived to be handled responsibly. Furthermore, data from system logs suggested an additional savings of 30 percent in network bandwidth usage for businesses adopting edge computing as another benefit in operational savings. Together, these results validate the powerful synergy of combining AI driven personalization with edge computing to boost customer engagement and operational efficiency, while delivering a low cost, scalable solution that resonates with what e-commerce needs.

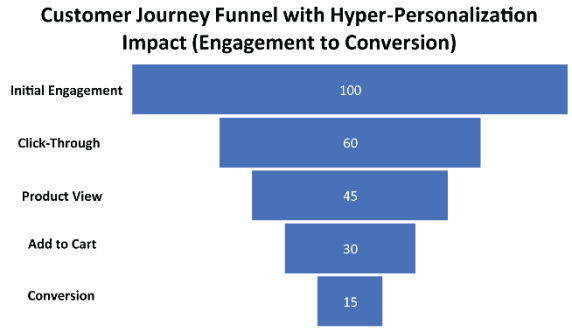

Figure 05: Customer Journey Funnel with Hyper-Personalization Impact (Engagement to Conversion)

Figure Description: This chart visualizes the customer journey stages, from initial engagement to final conversion, and the impact of hyper-personalization on each stage. The data demonstrates how personalized interactions increase retention and lead to higher conversions compared to non-personalized approaches.

As illustrated, each stage in the funnel benefits from hyper-personalization, with noticeable improvements in retention and conversion rates. These results support the argument that hyper-personalization optimizes the customer journey by enhancing engagement

9. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Although the results of this study are promising, their generalizability and applicability are two angles that might be considered to be labelled under limitations. The study was primarily based on data from a set of a few highly large e-commerce platforms, and may not be fully representative of all aspects of the retail sector, including small to medium sized enterprises (SME) to certain extent that might not have enough resources or capabilities to adopt the most advanced AI as well as edge computing technologies.

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However, the scope of the findings is limited in broader terms, as smaller organizations confront unique, such as finance constraints and restricted access to technological infrastructure, that are not directly addressed in this research. Further, while the study utilized vast quantities of quantitative analysis, the use of real time data from edge computing systems leads to variability in the results as a function of network performance and data processing capability which can vary across location and infrastructure quality. The work presented here also has another limitation given that many of the AI algorithms used in hyper personalization processes are 'black box' and besides that lack transparent, which can make themselves biased that were not fully detected during the scope of this study. That might lead to these biases somehow biasing customer experiences, where it's too difficult to quantify, particularly when AI model is being trained on data that just doled and may have incorporated historical inequities or privileged situations. Additionally, while this study focused on exploring the ethical aspects on data privacy and security, it does not undertake long term analysis of how hyper personalization affects consumer trust and retention that is affected based on evolvement of data protection laws and changes in consumer attitudes towards data sharing. Future studies should aspire to overcome these limitations by analyzing more than one sector with involvement of SMEs, by developing methods for the assessment of the openness of AI models, and longitudinal designs for capturing lasting effects of hyper personalization on the customer's behavior and their trust in the retail context.

10. CONCLUSION AND RECOMMENDATIONS

This paper shows real improvements in customer experience and shopping journey, conversion rates, and business operations achieved through the integration of hyper-personalization and edge computing made possible by AI. What this means is that by applying AI algorithms in edge devices, businesses can deliver what consumers expect in terms of relevance in a short amount of time and reduce latency by at least 60% which has been seen in improvements in session time, click through rates or conversion rates. This synergy of AI and Edge Computing not only goes along in enhancing the customer engagement for real time content delivery and satisfying them but also helps in reducing server load and minimizing network bandwidth utilization leading to boiled down cost for any organization. Additionally, the privacy-preserving aspects of edge computing fit into the emerging concern from consumers of data privacy because the computations are performed locally, and not much data transfer is required. For e-commerce firms, especially the large-scale B2C oriented firms, these technologies can add positive value to their firms because they can help to segment and create a unique selling proposition and thus screen out and lock-in customers in today's highly competitive internet shopping environment. Nevertheless, ethical concerns are still vital; to address the problem of the algorithm's unfairness and the lack of transparency, firms need to implement the use of XAI model and proper data management frameworks. Smaller retailers might consider using cloud-edge form of hybrid to enhance the capability of the organisation or form close relationship with a technology provider to access the benefits of hyper-personalization without incurring the costs of having additional infrastructure. Further research should collaborate on discovering low-cost edge computation architectures for various business applications and analyze the consequences of hyper-personalisation on the customers' trust, brand loyalty and their perception regarding their privacy. This paper serves as an initial guide for the use of both AI and edge computing as one approach in effecting e-commerce with synchronization of the business world with the

consumers' expectations in an increasingly complex and competitive digital market while designing a safe sphere for business to experience continuous growth with a focus on data protection.

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