ENHANCING SEO IN SINGLE-PAGE WEB APPLICATIONS IN CONTRAST WITH MULTI-PAGE APPLICATIONS

A SEMINAR REPORT

by

BENET PAUL BENNY (VJC21IT017)

in partial fulfillment for the award of the degree

of

BACHELOR OF TECHNOLOGY

in

INFORMATION TECHNOLOGY

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

DEPARTMENT OF INFORMATION TECHNOLOGY

VISWAJYOTHI COLLEGE OF ENGINEERING AND TECHNOLOGY, VAZHAKULAM

NOVEMBER 2024

ENHANCING SEO IN SINGLE-PAGE WEB APPLICATIONS IN CONTRAST WITH MULTI-PAGE APPLICATIONS

A SEMINAR REPORT

by

BENET PAUL BENNY (VJC21IT017)

in partial fulfillment for the award of the degree

of

BACHELOR OF TECHNOLOGY

in

INFORMATION TECHNOLOGY

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

under the guidance

of

Mrs. TINY MOLLY

Asst. Professor, IT Dept.

DEPARTMENT OF INFORMATION TECHNOLOGY

VISWAJYOTHI COLLEGE OF ENGINEERING AND TECHNOLOGY, VAZHAKULAM

NOVEMBER 2024

VISWAJYOTHI COLLEGE OF ENGINEERING AND TECHNOLOGY, VAZHAKULAM

Department of Information Technology

Vision

To be a centre of excellence in IT learning and provide value based training to mould students as successful IT professionals.

Mission

1. To provide an intellectually stimulating and academically vibrant learning environment for students and train them in the basic as well as advanced concepts, knowledge, technology and skills of IT.
2. To promote a nurturing and caring environment and prepare students to achieve their academic and career goals in a globally competitive marketplace.
3. To mould students into ethical and competent professionals who will contribute to the betterment of the community.

Program Educational Objectives

Our Graduates

1. Shall excel in programming skills, so as to make them professionally competent, innovative and socially uplifting the standard of life.
2. Shall have social values, sharpening their analytical skills to find solutions to the existing software problems.
3. Shall have positive attitude towards research and entrepreneurship.

Program Outcomes

1. **Engineering knowledge**:Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**:Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences
3. **Design / development of solutions**:Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems**:Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**:Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:**Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:**Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:**Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice
9. **Individual and team work:**Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:**Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and unread in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**:Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Program Specific Outcomes

1. Shall have knowledge on smart technologies in the field of IT and are well equipped with cutting edge technologies and concepts.
2. Shall bring in the advantages of technology into the society, so that it will accelerate the development and betterment of people.

VISWAJYOTHI COLLEGE OF ENGINEERING AND TECHNOLOGY,VAZHAKULAM
DEPARTMENT OF INFORMATION TECHNOLOGY

BONAFIDE CERTIFICATE

This is to certify that the Seminar report entitled **"Information Fusion and Hand Alignment to Improve Hand Recognition** is a bonafide record of the work by **BENET PAUL BENNY (VJC21IT017)** in partial fulfillment of the requirements for the award of the **Degree of Bachelor of Technology** in **Information Technology** of APJ Abdul Kalam Technological University.

Place : Vazhakulam

Date : .....

Mrs. Tiny Molly
Seminar Guide
Assistant Professor
Dept. of IT, VJCET

Mrs. Jesline Joseph
Seminar Coordinator
Assistant Professor and HOD
Dept. of IT, VJCET

Examiner

DECLARATION BY THE CANDIDATE

I hereby declare that the seminar report entitled ”Enhancing SEO in Single-Page Web Applications in Contrast With Multi-Page Applications” submitted by me to the Department of Information Technology, Viswajyothi College of Engineering Technology, Vazhakulam, Muvattupuzha in partial fulfillment of the requirement for the award of the degree of B.Tech in Information Technology is a record of bonafide seminar work carried out by me under the guidance of Mrs Tiny Molly Assistant Professor. I further declare that the work reported in this seminar has not been submitted and will not be submitted, either in part or in full, for the award of any other degree in this college.

Place : Vazhakulam

Date : .....

BENET PAUL BENNY

ACKNOWLEDGEMENT

First of all,and whole heartedly I thank God for giving me this opportunity for successful completion of my seminar work. I am immensely indebted to our beloved Manager **Msgr. Dr. Pius Malekandathil** , our beloved Director **Rev. Dr. Paul Parathazham** , for providing a good infrastructure with well-equipped labs.Our Principal **Dr. K K Rajan** deserves special mention for the moral support he has given to me. I assert beyond the confines of simple gratitude to the Head of the Department of IT and Seminar coordinator **Mrs. Jesline Joseph**, and Seminar guide **Mrs. Tiny Molly** for their very able guidance and valuable cooperation. Also, I would like to express our gratitude for their guidance and valuable suggestions and encouragement in this topic.

Unflinching support and constant encouragement from my friends helped me a long way to complete my seminar work. I thank them from the depth of our heart.

ABSTRACT

This paper comprehensively reviews methods for improving single-page applications' visibility (SPAs) and user experience, focusing on the intricacies of search engine optimisation (SEO). This research contrasts the complexities and challenges in optimising SEO in SPAs instead of conventional multi-page applications (MPAs). It identifies vital optimisation methods and evaluates their applicability in the contem- porary web landscape. The research method involves implementing the explored optimisation techniques across three distinct projects utilising emerging technologies for SPA, MPA, and a hybrid approach using Isomorphic JavaScript. These applications are systematically examined and subjected to a comparative analysis to assess the effectiveness of the optimisation strategies before and after applying the optimisation strategies. The empirical results substantiate that adopting an innovative approach to Client-Side rendering for the initial page load, combined with traditional SEO practices, performance enhancements, and tailored methodologies for specific technologies, facilitates SEO optimisation in SPAs at a level commensurate with MPAs. The findings of this work hold significant implications for web developers, offering insights and actionable strategies to augment visibility and performance in search engine results. By bridging the theoretical understanding with hands-on application and empirical analysis, the research contributes to the evolving field of web application development. It underscores the critical role of SEO optimisation in the context of SPAs, highlighting its importance for search engine rankings and overall user engagement and satisfaction.

Key Words:- JavaScript, search engines, single-page applications, web search.

Contents

List of Figures

List of Abbreviations

SPA Single-Page Application

MPA Multi-Page Application

SEO Search Engine Optimization

SSR Server-Side Rendering

CSR Client-Side Rendering

SSG Static Site Generation

ISR Incremental Static Regeneration

DSG Deferred Static Generation

CTR Click-Through Rate

FCP First Contentful Paint

LCP Largest Contentful Paint

CLS Cumulative Layout Shift

Chapter 1

INTRODUCTION

The rapid evolution of web technologies has transformed how applications are designed and delivered to users. In recent years, Single-Page Applications (SPAs) have gained substantial popularity among developers and users alike due to their ability to offer a seamless, app-like user experience within a web browser. SPAs dynamically load content without refreshing the entire page, enabling smoother interactions and faster transitions, making them highly effective for applications that require continuous user engagement, such as social media platforms, e-commerce sites, and real-time dashboards.

Unlike traditional Multi-Page Applications (MPAs), which follow a more straightforward architecture with distinct URLs for each page, SPAs work by loading a single HTML page initially. Further content is fetched asynchronously using JavaScript as users interact with the application. This design provides a more fluid experience but introduces unique challenges for Search Engine Optimization (SEO). Since SPAs rely heavily on JavaScript to load and render content, search engine crawlers may struggle to access or understand dynamically loaded content, leading to incomplete or inaccurate indexing. This affects the visibility of SPAs in search engine results pages (SERPs), which can ultimately limit user discovery and impact the website's reach.

On the other hand, Multi-Page Applications (MPAs) are composed of multiple pages, each with its own unique URL and static HTML content. MPAs load a new page from the server every time a user navigates to a different section of the site, resulting in a full page refresh for each interaction. Although MPAs may appear slower in terms of user experience, they offer distinct SEO advantages. Each page in an MPA is treated as a separate document by search engines, making it easier for crawlers to index content and assess relevance, thus improving the application's overall search visibility.

Since search engine algorithms prioritize content that is easily accessible, the dynamic loading of SPAs, which often requires JavaScript execution, can obscure important information from

crawlers. In cases where crawlers cannot execute JavaScript effectively, critical content may remain unindexed, leading to poor SEO performance. This issue is especially relevant as Google and other search engines increasingly rely on mobile-first indexing, which requires web content to be optimized for both desktop and mobile environments.

The SEO challenges in SPAs have spurred the development of advanced rendering techniques aimed at bridging this gap between SPAs and MPAs. This report specifically examines pre-rendering and Isomorphic JavaScript (also known as Universal JavaScript), two strategies that allow SPAs to serve fully-rendered HTML to search engines without sacrificing the interactive experience users expect. Pre-rendering involves generating static HTML files for each page at build time, enabling search engines to crawl the content without needing to execute JavaScript. Isomorphic JavaScript, on the other hand, combines Server-Side Rendering (SSR) with Client-Side Rendering (CSR). With this approach, initial page content is rendered on the server and sent as fully-formed HTML, which is then "hydrated" by JavaScript on the client side to enable dynamic interactions.

1.1 OBJECTIVES

This paper explores the unique SEO challenges of Single-Page Applications (SPAs) compared to Multi-Page Applications (MPAs), focusing on JavaScript-dependent content that can limit search engine visibility. By investigating pre-rendering and Isomorphic JavaScript techniques, this study aims to demonstrate how SPAs can achieve improved SEO performance. The objectives of this paper are:

1. **To analyze structural and technical SEO differences between SPAs and MPAs**: This objective examines how SPAs and MPAs differ in content delivery, rendering, and URL structure, impacting SEO practices. It highlights why SPAs face visibility challenges and explores the technical foundations behind these differences.
2. **To evaluate the impact of pre-rendering and Isomorphic JavaScript on SEO for SPAs**: By examining how pre-rendering (static HTML generation) and Isomorphic JavaScript (server-side rendering) enhance SEO, this study tests these techniques to measure their effect on SPA discoverability and indexing.
3. **To assess SEO performance improvements using these techniques**: Through empirical data from optimized SPAs, this paper offers insights for developers and businesses seeking to enhance SEO in SPAs without compromising user interactivity.

Chapter 2

RELATED WORKS

2.1 SEO in Multi-Page Applications (MPAs)

Multi-Page Applications (MPAs) are commonly used in web development due to their straightforward SEO advantages. Each page in an MPA is served as a unique HTML document with its own URL, fully rendered server-side before it reaches the client. This design allows search engines to crawl and index each page independently, as the content is presented in a static format that doesn't require JavaScript execution to be visible. Research consistently shows that MPAs have a natural advantage in search engine discoverability because of their content stability and ease of access for crawlers, which aligns well with traditional SEO techniques. These characteristics make MPAs ideal for content-heavy sites, where distinct sections need to be visible individually in search results, such as e-commerce sites, news portals, and blogs.

2.2 SEO in Single-Page Applications (SPAs)

Single-Page Applications (SPAs) offer a smooth, app-like experience by dynamically loading content on a single page. This interactive experience is achieved by updating the page via JavaScript without reloading, which allows faster transitions and better user engagement. However, the JavaScript-dependency of SPAs introduces significant challenges for SEO, as search engine crawlers may struggle to render and index content that is dynamically loaded. Studies on SPAs and SEO indicate that the reliance on client-side rendering (CSR) can limit search engine visibility since crawlers may not fully execute JavaScript. As a result, key content may be missing from search engine indexes, reducing the effectiveness of SPAs in attracting organic traffic. Researchers have highlighted that SPAs need specific SEO optimizations, such as structured data and rendering enhancements, to improve accessibility for crawlers.

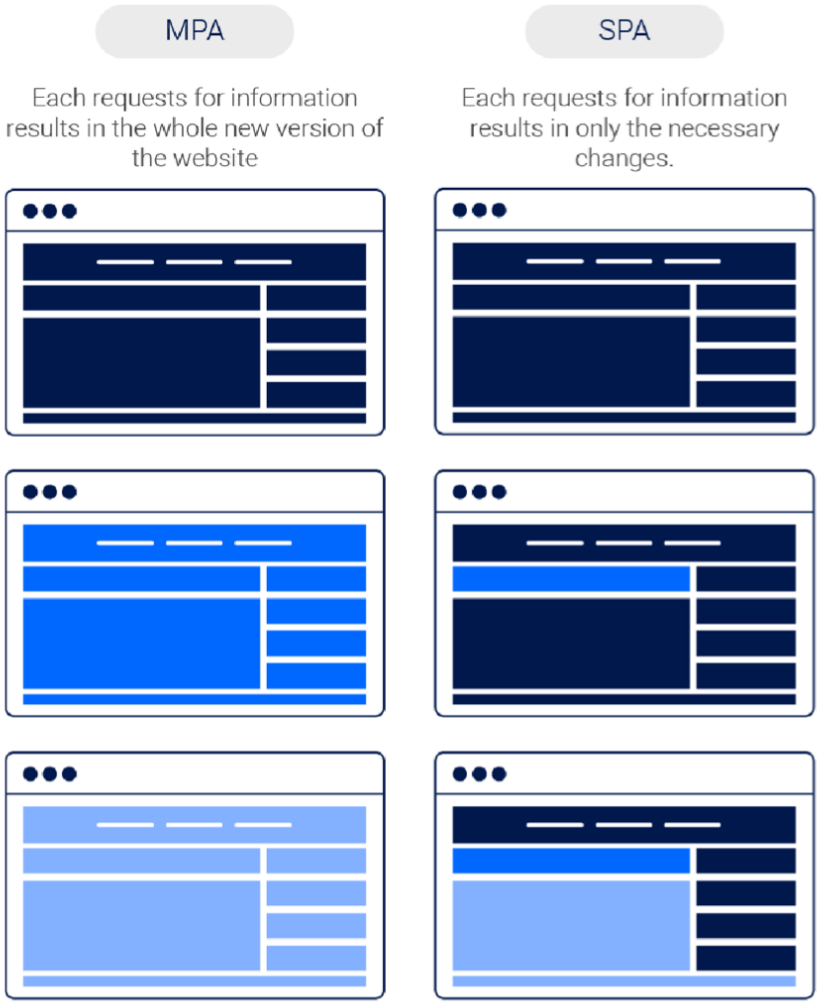

Figure 2.1: View update in SPA and MPA - a comparison.

2.3 Current Approaches and Limitations

To address the SEO challenges in SPAs, current approaches such as Server-Side Rendering (SSR) and Client-Side Rendering (CSR) offer partial solutions. SSR involves rendering HTML content on the server and sending it to the client, making initial content more accessible to search engines. CSR, while beneficial for dynamic user interactions, requires search engines to process JavaScript to fully index content, which can lead to incomplete indexing. Each of these methods has inherent trade-offs; SSR can improve crawlability but may increase server load and complexity, while CSR offers flexibility at the cost of potential SEO limitations.

These limitations have led to further exploration of pre-rendering and Isomorphic JavaScript (Universal JavaScript). Pre-rendering generates static HTML at build time, ensuring that content is available to search engines without requiring JavaScript execution. Isomorphic JavaScript, which allows JavaScript to run on both the server and client, enables SPAs to initially render content server-side for improved SEO while retaining client-side interactivity. These advanced techniques

are emerging as promising solutions to balance SEO needs with the dynamic functionality of SPAs, paving the way for optimized discoverability in SPAs without compromising user experience.

Chapter 3

PROPOSED MODEL

Optimizing SEO for Single-Page Applications (SPAs) presents unique challenges due to their client-side rendering (CSR) model, where JavaScript dynamically loads content after the initial page load. This method enhances user experience with smoother transitions and faster interactions, but it complicates SEO, as search engine bots may not fully execute or interpret JavaScript-based content. This reliance on JavaScript can lead to incomplete indexing, reducing search engine visibility for SPA content. By contrast, Multi-Page Applications (MPAs) are rendered on the server and deliver fully-formed HTML for each unique URL, allowing search engines to crawl and index each page easily. This server-rendered content structure aligns well with traditional SEO practices, as crawlers can readily access and catalog content.

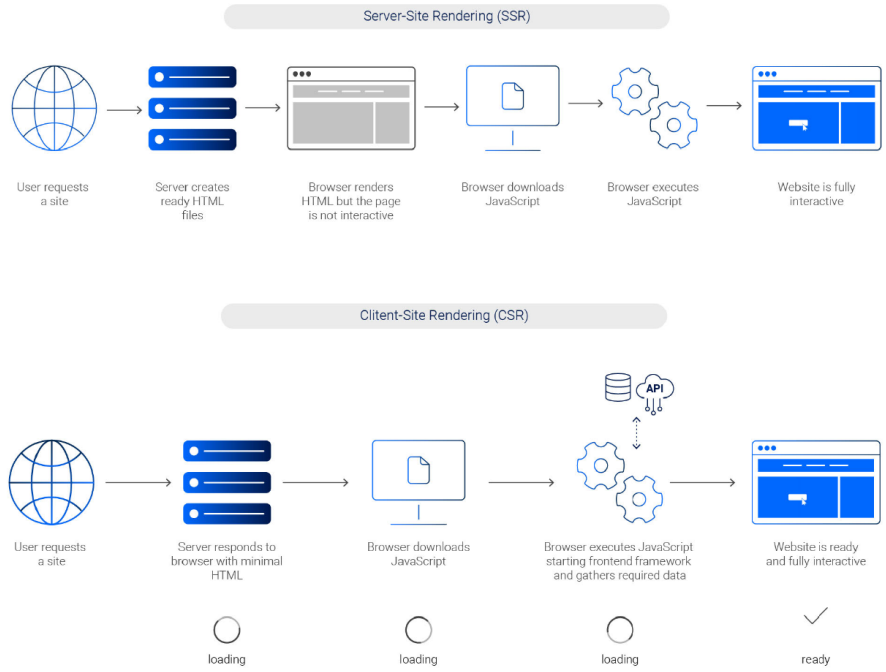

Figure 3.1: Rendering methods for web applications: SSR and CSR.

The proposed model aims to address these SEO limitations in SPAs by using pre-rendering and

Isomorphic JavaScript. These techniques are designed to make SPA content more accessible to crawlers without compromising the interactive benefits SPAs offer to users. By integrating these approaches, the model ensures that search engines can detect and index key content elements in SPAs, bridging the SEO performance gap between SPAs and MPAs.

3.1 Comparison of Pre-rendering and Isomorphic JavaScript

To overcome SEO challenges in SPAs, this model employs two primary techniques:

1. **Pre-rendering**: In this approach, static HTML is generated at build time for each page. This pre-rendered HTML is served to search engines and users alike, ensuring that content is accessible without requiring JavaScript execution. Pre-rendering is particularly beneficial for SPAs that need SEO optimization for static content that doesn't change frequently, as it offers fast loading times and is easy for search engines to index.

2. **Isomorphic JavaScript (Universal JavaScript)**: This technique combines Server-Side Rendering (SSR) with Client-Side Rendering (CSR), allowing the initial HTML to be rendered on the server before handing over control to the client. When a page is first loaded, the server sends fully-rendered HTML, allowing search engines to immediately access and index the content. After this initial load, JavaScript takes over on the client side, providing interactivity and dynamic updates. This hybrid model offers the SEO benefits of server-rendered HTML with the interactive advantages of client-side JavaScript, making it a strong choice for SPAs with dynamic content requirements.

3.2 Tools and Techniques Used for SEO Optimization

To measure and optimize SEO improvements in SPAs, the proposed model uses a combination of SEO analysis tools:

1. **Seobility**: This tool provides insights into a website's overall SEO performance by evaluating factors such as meta tags, keyword optimization, and internal linking. For SPAs, Seobility highlights areas where dynamic content may be missing from search engine indexing.

2. **Google PageSpeed Insights**: This tool assesses page load times and performance on both mobile and desktop devices. Since speed is a critical SEO factor, especially in SPAs, PageSpeed Insights offers recommendations on how to improve page loading and interactivity, which impact user experience and search engine rankings.

3. **Lighthouse**: An open-source tool by Google, Lighthouse runs audits on performance, accessibility, SEO, and more. For SPAs, Lighthouse helps identify SEO issues related to JavaScript execution, load times, and metadata structure, providing actionable insights for optimizing search engine visibility.

These tools are instrumental in assessing content visibility, load speed, metadata accuracy, and overall SEO health for SPAs. By combining these techniques and tools, the proposed model aims to balance the user experience advantages of SPAs with the SEO strengths of MPAs, enhancing the accessibility of SPA content to search engines and ensuring a higher SEO score.

Chapter 4

EXPERIMENT AND IMPLEMENTATION

To assess the effectiveness of SEO optimizations in Single-Page Applications (SPAs) versus Multi-Page Applications (MPAs), a comparative experiment was designed using three versions of a prototype application: a Flask-based MPA, a React-based SPA, and a Next.js-based SPA utilizing pre-rendering and server-side rendering (SSR). Each version of the application served as a test case for different rendering and SEO strategies, allowing for a controlled evaluation of how well each approach supports search engine visibility and crawlability. This setup enabled the comparison of static MPA rendering against client-side and hybrid server-client rendering in SPAs, providing insights into the performance and SEO advantages each method offers.

4.1 Testing Environment and Tools

The testing was conducted in a simulated environment replicating real-world web conditions, focusing on SEO-relevant metrics such as load time, crawlability, and content indexing success. To ensure a comprehensive evaluation, the following SEO analysis tools were used:

1. **Seobility**: Provided an in-depth SEO audit, evaluating each application's metadata, keyword optimization, internal linking structure, and content accessibility to search engines.
2. **Google PageSpeed Insights**: Used to measure page load times and user experience metrics. This tool helped assess the speed and responsiveness of each version, factors that directly impact SEO performance.
3. **Lighthouse**: Analyzed various aspects of SEO, including page accessibility and overall search engine readiness, especially for JavaScript-heavy content in SPAs.

The testing environment aimed to provide consistent and objective measures of SEO performance across the three applications, focusing on the ease of indexing dynamic versus static content, and the impact of rendering methods on load times.

4.2 Optimization Techniques Applied

Each version of the application utilized specific SEO and rendering techniques aligned with the architecture of its respective framework:

1. **Flask (MPA)**: This version represented a traditional MPA setup with each page rendered on the server. Since each page was pre-rendered on the server, the application could deliver static HTML directly to users and search engines, making all content immediately accessible. Unique meta tags and descriptions were assigned to each page, ensuring that each URL targeted specific keywords and had optimized metadata for improved ranking potential. SEO-friendly URLs were also implemented, avoiding unnecessary parameters and enhancing readability for both users and search engines. Additionally, structured data markup was added, allowing search engines to understand content context more accurately and display rich snippets where possible. To optimize performance, server-side caching was applied, reducing page load times and enhancing user experience—a factor that indirectly boosts SEO by minimizing bounce rates. Internal linking across pages helped distribute SEO value, ensuring comprehensive indexing of the site. Altogether, these techniques allowed the MPA to maintain a high level of SEO compatibility, capitalizing on its static, server-rendered structure to achieve optimal search engine visibility.

2. **React (CSR SPA)**: The React-based SPA relied on client-side rendering (CSR), additional techniques were applied to address the inherent SEO challenges of JavaScript-based content. Meta tags, Open Graph tags, and Twitter Card tags were carefully added to ensure that even dynamic pages had descriptive metadata, helping crawlers identify content themes and improving social media sharing compatibility. React Helmet was utilized to dynamically manage metadata on a per-page basis, allowing individual pages to have unique titles and descriptions despite being part of a single-page structure. Lazy loading was applied to images and media, ensuring assets loaded only when necessary, reducing initial load times and enhancing user experience—a critical factor in SEO. Progressive enhancement was also implemented, so users with limited JavaScript capability could access key information, making basic content accessible to a broader audience. Although CSR limits direct crawlability, these optimizations aimed to maximize metadata accuracy and performance, indirectly boosting SEO through improved user engagement.

3. **Next.js (Pre-rendered SPA)**:Both Static Site Generation (SSG) and Server-Side Rendering (SSR) were applied to optimize SEO while preserving the dynamic experience typical of SPAs. For static content that didn't change frequently, Static Site Generation (SSG) was used to generate fully-rendered HTML files at build time. This ensured that key pages were ac-

cessible without JavaScript execution, significantly improving indexing and load times. For pages requiring user-specific or frequently updated data, SSR was implemented, enabling the server to render content upon request and deliver complete HTML to search engines and users. Incremental Static Regeneration (ISR) was used on specific pages that needed occasional updates, enabling static content to refresh at intervals without rebuilding the entire site, keeping content relevant and improving SEO without sacrificing performance. Next.js's native support for code splitting and asset optimization allowed JavaScript files to load incrementally, further reducing load times. Together, SSG, SSR, and ISR provided an ideal balance of static and dynamic rendering, enhancing SEO while preserving the interactivity that defines SPAs. The combination of these techniques allowed the Next.js SPA to achieve high search engine visibility while maintaining optimal user experience.

These optimization techniques provided a range of SEO solutions across different application architectures, allowing for a comprehensive evaluation of each rendering approach's impact on search engine accessibility and user experience.

Chapter 5

RESULTS AND ANALYSIS

To assess the SEO effectiveness of each method, performance was evaluated based on key SEO metrics such as content crawlability, page load speed, and mobile responsiveness. These metrics are crucial for determining a website's visibility and ranking potential in search engines. The Next.js pre-rendered SPA consistently showed the highest scores across all metrics, indicating that pre-rendered static HTML content was easily accessible to search engine crawlers. This made Next.js particularly effective at optimizing SPAs for search engine discoverability, as it provided quick and complete content for indexing without relying solely on JavaScript. The Flask-based MPA, which used traditional server-rendered pages, also scored highly, demonstrating that server-side rendering provides a clear SEO advantage in terms of fast, accessible content. In contrast, the React-based CSR SPA had lower scores, primarily due to the reliance on client-side JavaScript for rendering content, which made certain elements less accessible to search engines and impacted load speeds.

5.1 Comparison of SEO Scores in SPAs vs. MPAs

The SEO scores revealed a significant difference between SPAs with pre-rendering or SSR capabilities and CSR-only SPAs. The pre-rendered Next.js SPA achieved SEO scores that were comparable to the MPA, underscoring that a pre-rendered SPA can meet similar SEO standards as a traditional MPA when server-side techniques are applied. The Flask MPA benefited from its static, server-rendered content, which is easily indexed and thus naturally SEO-friendly. In comparison, the React CSR SPA had lower SEO scores because the dynamically loaded content was not fully accessible to crawlers, and the reliance on JavaScript delayed some content loading. This result highlights the importance of server-rendered or pre-rendered content in achieving effective SEO, especially for SPAs that need to ensure their content is fully visible to search engines.

5.2 Effectiveness of Pre-rendering and Isomorphic JavaScript

Both pre-rendering and Isomorphic JavaScript significantly improved SEO outcomes for SPAs by addressing the content accessibility challenges posed by client-side rendering. Pre-rendering allowed the Next.js SPA to deliver static HTML directly to search engine crawlers, ensuring that important content could be indexed without relying on JavaScript execution. This approach improved SEO metrics by ensuring faster initial load times and full content visibility. Isomorphic JavaScript, which combines SSR and CSR, was effective in providing a hybrid solution: it enabled fast initial loading through server-rendered HTML, while allowing client-side interactivity post-load. This technique balanced the SEO advantages of server-rendered content with the dynamic capabilities SPAs are known for, demonstrating that Isomorphic JavaScript can make SPAs both user- and search engine-friendly. The results show that implementing pre-rendering or Isomorphic JavaScript in SPAs can achieve SEO performance similar to that of MPAs, offering a viable approach to optimizing SPAs for search engine visibility without compromising the user experience.

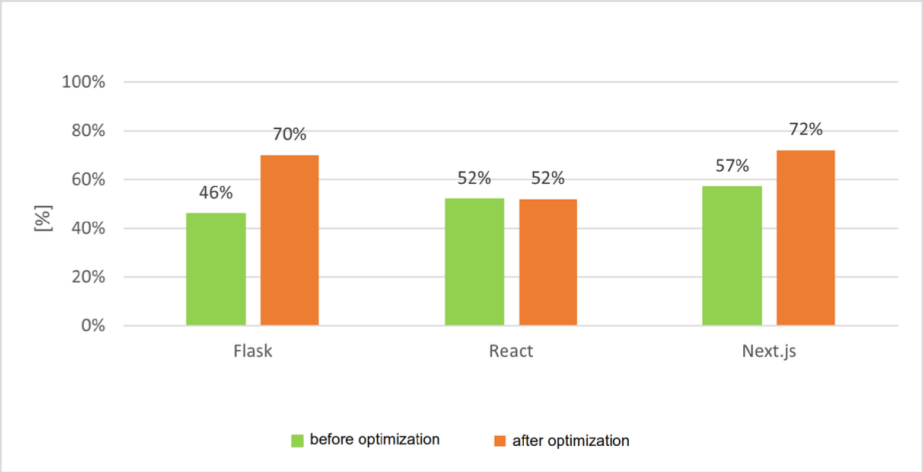

Figure 5.1: Overall SEO score - Seobility.

Each of these findings highlights the effectiveness of using pre-rendering and Isomorphic JavaScript to overcome SEO limitations in SPAs, with metrics showing improvements in visibility, indexing, and page performance that are comparable to MPAs.

Chapter 6

CONCLUSION

This study sheds light on the SEO challenges that traditional Single-Page Applications (SPAs) face due to their reliance on client-side rendering, which often limits search engine visibility. Through comparative analysis, the study demonstrates that advanced rendering techniques, specifically pre-rendering and Isomorphic JavaScript, can significantly enhance the SEO performance of SPAs, bringing them closer to the search engine accessibility seen in Multi-Page Applications (MPAs). By utilizing these techniques, developers can overcome limitations in SPA content discoverability, achieving higher SEO scores and ensuring essential content is indexed by search engines.

Pre-rendering allows SPAs to serve static HTML at build time, making content readily available for indexing without needing JavaScript execution, which improves load times and crawlability. On the other hand, Isomorphic JavaScript offers a hybrid solution, where initial content is server-rendered for SEO and then dynamically updated on the client side, allowing SPAs to retain interactivity while remaining SEO-friendly.

The findings confirm that these strategies can effectively bridge the gap between SPAs and MPAs, enabling SPAs to retain their smooth user experience without compromising on SEO. For future research, Incremental Static Regeneration (ISR) presents an exciting area of exploration, allowing SPAs to dynamically refresh specific pages while preserving static content benefits. Adopting ISR could provide a powerful solution for maintaining content freshness and SEO performance, paving the way for more adaptable and SEO-optimized SPAs. This work contributes to evolving web development practices, offering practical approaches to build modern, SEO-optimized applications that meet both user and search engine requirements.

References

[1] A. Van Looy, “Search engine optimization,” in Social Media Manage- ment: Using Social Media as a Business Instrument. Springer, 2022, pp. 125–146.

[2] S. Das, Search Engine Optimization and Marketing: A Recipe for Success in Digital Marketing. Boca Raton, FL, USA: CRC Press, 2021.

[3] M. R. Baye, B. De los Santos, and M. R. Wildenbeest, “Search engine optimization: What drives organic traffic to retail sites?” J. Econ. Manage. Strategy, vol. 25, no. 1, pp. 6–31, Mar. 2016.

[4] D. Mladenović, A. Rajapakse, N. Kožuljević, and Y. Shukla, “Search engine optimization (SEO) for digital marketers: Exploring determinants of online search visibility for blood bank service,” Online Inf. Rev., vol. 47, no. 4, pp. 661–679, Jul. 2023.

[5] P. Petrescu. (Oct. 1, 2014). Google Organic Click-Through Rates in 2014. MOZ Blog. Accessed: May 30, 2016.

[6] E. Fubel, N. M. Groll, P. Gundlach, Q. Han, and M. Kaiser, “Beyond rankings: Exploring the impact of SERP features on organic click-through rates,” 2023, arXiv:2306.01785.

[7] L.-C. Chen, “A study of optimizing search engine results through user interaction,” IEEE Access, vol. 8, pp. 79024–79045, 2020.

[8] A. R. Terrance, S. Shrivastava, and A. Kumari, “Importance of search engine marketing in the digital world,” in Proc. ICITKM, vol. 14, 2017, pp. 155–158

[9] D. Lewandowski and S. Schultheiß, “Public awareness and attitudes towards search engine optimization,” Behav. Inf. Technol., vol. 42, no. 8, pp. 1025–1044, Jun. 2023

[10] S. Schultheiß and D. Lewandowski, “Misplaced trust? The relationship between trust, ability to identify commercially influenced results and search engine preference,” J. Inf. Sci., vol. 49, no. 3, pp. 609–623, Jun. 2023.