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Dynamic Overlay Systems for Real-Time Infotainment Personalization

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Abstract

As automotive infotainment systems become increasingly complex, personalization and brand differentiation have emerged as critical aspects of the user experience. Traditional static UI architectures, reliant on predefined themes and fixed UI elements, struggle to accommodate real-time dynamic adaptations based on contextual factors such as brand identity, driver preferences, location, and vehicle mode. To address this challenge, this article explores a Dynamic Overlay System, leveraging Runtime Resource Overlays (RRO) to enable adaptive UI customization at runtime while maintaining system modularity and performance. This approach structures infotainment resources into dedicated brand and display-specific overlay directories, allowing seamless adaptation across diverse screen configurations, including Freeform 32-inch, 11-inch, and 16-inch portrait displays. It enables dynamic UI adjustments without modifying core application logic, improving both maintainability and scalability. By utilizing structured Android.bp, .mk files, and overlay resource handling, the system ensures efficient integration with Android-based automotive platforms, facilitating scalable, theme-driven UI customization. The article also compares alternative industry approaches, such as static theming, dynamic overlays, and cloud-based UI updates, demonstrating how RRO-based systems offer superior flexibility and efficiency. Furthermore, we explore potential future extensions, including AI-driven UI adaptation, Over-the-Air (OTA) customization, and cloud-based theme deployment, ensuring infotainment ecosystems remain adaptable to evolving consumer demands. With a focus on technical implementation, industry best practices, and real-world usability, this article provides architecture diagrams, Android.bp/.mk configuration examples, and in-depth code breakdowns—offering practical insights for developers and engineers aiming to enhance infotainment personalization while maintaining system integrity

Keywords: Automotive Infotainment, Dynamic Overlay Systems, Real-Time Personalization, Runtime Resource Overlays (RRO), Adaptive UI, Brand-Specific Customization, Theming and Resource Management, Android.bp, Android.mk, Multi-Screen Support, Freeform Display, Modular UI Design, OTA UI Updates, Context-Aware Interfaces, AI-Driven UI Adaptation, Cloud-Based Theming

I. Introduction

Modern automotive infotainment systems are evolving at an unprecedented pace. With the rise of digital cockpits, personalized user experiences, and multi-display environments, manufacturers are seeking ways to provide dynamic and context-aware user interfaces. Infotainment systems are no longer just a dashboard feature; they serve as the central hub for vehicle interaction, combining navigation, media, climate control, and driver assistance. As automotive manufacturers cater to different brands, trim levels, and regional requirements, they must provide distinct user experiences without increasing development complexity. Traditionally, infotainment systems have relied on static theming, pre-defined layouts, or duplicating resources for each brand, which leads to maintenance overhead and scalability issues. To solve these challenges, **Dynamic Overlay Systems** enable real-time infotainment personalization, adapting to the driver's preferences, location, time of day, and even vehicle mode.

A. *Challenges in Infortainment Personalization*

1) *Multiscreen compatibility:* With the rise of various display configurations—ranging from 11-inch head units to 32-inch freeform displays—infotainment interfaces must dynamically adjust layouts and components. Each vehicle model may have different resolutions, aspect ratios, and interaction methods (touch, rotary controllers, or voice input). Hardcoding layouts for each screen is inefficient, requiring a more scalable approach.

2) *Theming Inconsistencies Across Brands:* Automotive brands often require unique UI themes, branding colors, and component variations, which complicates UI development. Runtime Resource Overlay (RRO) in Android has been a common solution for XML-based theming, but its applicability to Jetpack Compose-based UI elements remains a challenge. Without a structured approach to overlays, maintaining a cohesive yet brand-distinct interface becomes cumbersome.

3) *Managing Overlays and UI Customization:* Overlays provide a flexible way to modify UI components dynamically without affecting base implementations. However, existing solutions often require deep modifications to the application structure. Ensuring that overlays are efficiently applied at runtime, without performance degradation or redundant resource usage, is a crucial aspect of a well-architected infotainment system.

B. *Limitation of Resource Overlay in Jetpack compose*

RRO has proven to be an effective tool for separating brand-specific resources from core application logic. It allows assets like drawables, fonts, XML layouts, and strings to be overridden based on different OEM needs. However, Jetpack Compose—the declarative UI toolkit rapidly becoming the standard in automotive UI development—does not natively support RRO. Since Compose renders UI using Kotlin code instead of XML, traditional overlay techniques require new strategies to maintain dynamic customization capabilities.

C. *Competing Approaches*

Several methodologies have been explored to handle multi-brand, multi-display infotainment systems, but each has its own set of limitations:

1) *Static Theming:* Predefined styles and themes are set at compile-time, limiting runtime flexibility.
2) *A Manual Resource Swapping*: Brands and screen sizes manually load different UI elements at runtime, often leading to performance bottlenecks.
3) *A Hardcoded Layout Variants*: Multiple layouts for different brands result in increased maintenance overhead and redundant UI code.
4) *Custom Overlays Using Reflection or Dependency Injection*: Dynamic overlays can be injected into the UI framework, but they come with added complexity and runtime risks.

While these approaches offer partial solutions, they lack the scalability, efficiency, and seamless adaptability required for next-generation automotive infotainment. A robust Dynamic Overlay System is needed—one that seamlessly integrates into Jetpack Compose while supporting real-time updates and efficient resource management.

This article explores an advanced **Dynamic Overlay System for Real-Time Infotainment Personalization**, discussing its architecture, implementation strategies, and industry applications in detail.

II. Architecture of Dynamic Overlay Systems

Dynamic overlay systems form the backbone of real-time infotainment personalization in Android-based automotive platforms. At their core, these systems allow the vehicle's software to re-skin or adjust the user interface dynamically—changing colors, layouts, or feature visibility—without altering the underlying application logic. Android's **Runtime Resource Overlay (RRO)** framework enables this by layering overlay packages on top of base apps, effectively superseding certain resources at runtime for brand, model, or user-specific variations [1]. The overlay packages reside in the infotainment stack as separate modules, ensuring that when the system or an app requests a UI resource (such as a string, color, or layout), the overlay's value is returned instead of the original definition [1]. This indirection is fundamental to how automotive software can adapt multiple user experiences on the same core platform [2].

A. *Overlay Structure Within the Infotainment Stack*

In an Android Automotive environment, overlays typically appear in a tiered fashion. Build-time overlays are introduced during system compilation to handle base theming or brand distinctions; at runtime, **RRO** layers can take precedence over these build-time definitions, allowing a more dynamic approach to resource management [3]. Each overlay is packaged like a standard APK, containing resource overrides declared in a manifest. When installed, the overlay must specify which target app it supersedes, along with any system properties that govern activation (for instance, a property indicating brand or model line). Only the overlay corresponding to the car's actual configuration is activated, leaving inactive overlays dormant and thus not consuming runtime resources [3]. Because RROs cannot add entirely new resources—only override existing ones—the base application's contract remains intact while its final visual output transforms significantly. This technique ensures a **clean separation** between application logic and UI presentation [4].

B. *Jetpack Compose Integration for Runtime UI Adapation*

In With **Jetpack Compose** emerging as a modern, declarative UI toolkit, the question arises: how do overlay mechanisms integrate with a framework traditionally optimized for XML resources? Compose relies heavily on Kotlin code and real-time recomposition rather than static XML layouts [5]. Some industry practitioners overcome these limitations by storing themable or brand-specific parameters (colors, dimension scales, or typefaces) in resource form, then reading them into Compose code at runtime [6]. This approach preserves the modularity of RRO while leveraging Compose's state-driven redraw. As soon as an overlay changes the resource values (say, a different color scheme for a "Night Mode"), the Compose layer can recompose the UI, instantly providing a new look without losing the user's application state [5]. Such a synergy offers a "best of both worlds" scenario: the resource-centric overlay concept merges seamlessly with Compose's dynamic re-rendering model.

C. Multi-Screen and Multi-Brand Environment Handling

Modern vehicles often incorporate multiple displays—for example, a main infotainment display, a digital instrument cluster, and possibly a secondary passenger screen [7]. A dynamic overlay system must gracefully accommodate each display's resolution, orientation, and functional role. One best practice is to design a "lowest common denominator" approach for shared UI components, scaling up or re-laying them for larger or more specialized screens. Resource qualifiers or conditional overlays can then refine the UI based on each display's unique parameters [8]. Similarly, **multi-brand** scenarios demand fine-grained overlay activation: automotive OEMs often bundle multiple brand overlays into a single software image, letting a system property (like *ro.oem.brand*) determine which overlay to activate at boot [4]. This way, the same underlying software platform can adapt not only to multiple displays but also to entirely different brand aesthetics. The brand overlays typically override drawables, fonts, color palettes, and layout specifics, ensuring each brand's infotainment experience remains distinct. With each brand's overlay package lying dormant unless its respective property is set, the memory footprint remains controlled, and any potential conflict among multiple overlays is averted by strict priority rules [2], [4].

D. Dynamic Updates and Cloud-Driven Overlay Configurations.

One key advantage of using a dynamic overlay architecture is the potential for **post-deployment updates**. Rather than shipping an entirely new firmware image to update the vehicle's UI, developers can push out updated overlay packages that the infotainment system installs and enables on the fly [3]. This reduces the complexity of refreshing the software, whether for introducing seasonal themes or responding to user feedback on UI design. Additionally, the future potential for **cloud-driven personalization** grows significantly with overlays. For instance, the driver could select a custom accent color or new layout style from a companion mobile app, which a back-end service packages as an overlay and delivers OTA to the car [6]. The infotainment system then toggles the relevant overlay, providing an almost instant transformation of the UI's visuals. While the existing RRO infrastructure handles local resource overrides gracefully, caution is necessary when scaling to cloud-based workflows. Signature verification of overlay APKs, version compatibility checks, and rollback mechanisms (in case an overlay fails to load properly) must be carefully implemented to maintain software stability and security [7].

E. Best Practices and Technical Considerations

A robust overlay architecture for automotive infotainment should adhere to principles that balance flexibility, performance, and maintainability. One guiding principle is to confine the overlay strictly to **presentation-layer concerns** [1]. By avoiding logic injection, the overlay can freely morph the UI's styling, arrangement, or textual content without risking behavioral inconsistencies. Another principle is **minimal performance impact**, as excessive or redundant resource overrides may slow load times, especially when a brand or screen scenario triggers frequent resource lookups [2]. Testing under diverse conditions—multi-language, day/night mode, and multiple screen sizes—helps confirm that overlays remain stable across edge cases [5]. Where Jetpack Compose is involved, the recommended pattern is to store themable parameters in resource form, then convert them to Compose states, ensuring that a change in resource value triggers a recompose in real time [6]. Finally, layering the **Car UI Library** or official Android Automotive UI libraries beneath brand-specific overlays is a proven approach, as it leverages Google-tested design patterns while still affording each OEM the freedom to customize the user-facing elements [7]. In multi-screen scenarios, it is often beneficial to keep separate sets of overlay resources for each display type, preventing accidental cross-display overrides and maintaining clarity in the resource hierarchy [8]. By embracing these practices, automotive engineers can deliver a truly adaptive, updatable, and brand-faithful infotainment experience.

III. IMPLEMENTATION AND PRACTICLE STRATEGIES

A robust overlay architecture in Android-based automotive infotainment demands careful planning around how resources are structured, deployed, and iterated upon. Building on the layered approach introduced earlier, this section details practical methods that developers can follow when implementing dynamic overlay systems for real-time personalization. By combining thoughtful compile-time processes, flexible runtime resource packaging, Jetpack Compose integration, multi-screen consistency checks, OTA-friendly deployment, and a systematic performance validation plan, automotive developers can produce an adaptive UI foundation that meets evolving brand and user demands.

In broader terms, the strategies here emphasize maintaining a clean separation of concerns: one layer for base logic, another for brand or display differences, and a final overlay or dynamic factor for user-specific preferences or ephemeral states. This approach not only keeps code maintainable—by isolating theming and branding into dedicated modules—but also ensures that the core app remains stable even if brand configurations or overlays update frequently. Each strategy below addresses specific points in the development lifecycle, from building the software to testing it under real-world in-vehicle conditions.

A. Compile Time Configurations

Many teams begin by defining a **default "baseline" codebase** and resource set, typically stored in the main Android Automotive or AOSP branch. This baseline functions as a fallback in case no overlays are activated, guaranteeing that every vehicle at least has a working infotainment interface [1]. Often, brand or model-specific overlays supplement this baseline at compile time, injecting new color schemes, images, or layout modifications. This compile-time injection might involve a Gradle sub-project dedicated to each major brand or display scenario, so that build scripts automatically include the relevant sub-project for the final system image. In doing so, the overhead of brand management is partially automated: if you add a new brand sub-project with its resources, the build system merges them into the final image as overlays, ready for runtime selection. However, not all OEMs rely solely on compile-time brand differences. Many prefer a "layered" approach: baseline resources are set first, certain brand overlays are applied at compile time for widely used brand assets, and more granular overlays (like special holiday themes or newly introduced trim-level styling) remain as **post-build RRO packages** to be installed or toggled at runtime [2]. This multi-tier system offers a balance between consistency—ensuring major brand distinctions are baked into each build—and flexibility—allowing smaller or time-sensitive changes to be delivered as lightweight updates after the vehicle is on the road. Additionally, if developers keep the overlay resource structure consistent (naming conventions, folder hierarchies), they can easily incorporate new brand modules down the line without needing to reorganize the entire project. In practice, creating a brand-specific overlay often involves a minimal build file that references the baseline codebase. **Code Snippet 1** below provides a placeholder snippet demonstrating how an *Android.bp* file might declare an overlay module for a brand named **BrandX**. Note that this code does not include real brand assets, but indicates the overall structure and references:

```
// Code Snippet 1: Placeholder Android.bp for BrandX Overlay
android_app {
   name: "BrandX_overlay",
   srcs: [],
   resource_dirs: ["resBrandX"],  // brand-specific resource folder
   product_specific: true,
   manifest: "AndroidManifest.xml",
   required: [":baseline_app"],
   overrides: ["baseline_app"],
}
```

Using a dedicated resource folder (*resBrandX*) ensures that the overlay's drawables and layouts remain isolated from the baseline. This approach streamlines updates if **BrandX** requires additional or revised files, while leaving the core logic unmodified [16].

B. *Runtime Resource Packaging*

While compile-time overlays set a strong baseline, the power of Android's **Runtime Resource Overlay (RRO)** lies in its ability to override or augment resources without altering the compiled application code [1]. OEMs typically bundle each overlay in an APK that references existing resource IDs from the baseline. Whenever the system or user triggers a brand switch, a screen rotation, or a theming toggle, Android's resource resolution logic consults the overlay first, returning the brand- or scenario-specific asset instead of the default one. This mechanism effectively decouples theming from logic, allowing multiple brand or model overlays to coexist in the same system image. Only the overlay matching the current environment is activated, preventing conflicts or memory overhead from non-applicable packages [3]. Automotive developers often define a small service or system property check that runs at system boot to determine which overlay to enable. A property like *ro.oem.brand* might read "*BrandX*," prompting the system to mount or enable the *BrandX_overlay.apk.* Some teams go further and define additional properties (e.g., *ro.display.type=portrait_11in*), ensuring that the correct overlay for a portrait 11-inch head unit also gets applied [5]. Even multiple overlays can stack if needed—such as brand plus day/night overlays—though it is essential to assign overlay priorities carefully to avoid collisions. By referencing the same resource IDs in the baseline, each brand or scenario modifies only the aspect they care about (drawables, strings, layout variations), preserving the rest of the UI logic intact.

C. *Jetpack Compose Integration*

Marrying dynamic overlays to **Jetpack Compose**-based UIs introduces unique challenges and opportunities. Compose relies on declarative Kotlin code rather than static XML layouts, reducing the direct role that RRO can play. One approach is to store themable data (colors, dimension multipliers, typography sets) in resource form, then inject them into Compose's theming system at runtime [9]. For instance, the *ThemeOverlay* composable could fetch color resources from the overlay and pass them into a *MaterialTheme* block. When an overlay toggles, the resource references shift, prompting Compose to recompose. This near-real-time re-theming was traditionally difficult with XML-based layouts, which often required re-inflation or activity restarts. Because Compose is still evolving in the automotive domain, some OEMs adopt a hybrid strategy: they rely on conventional RRO for broad, brand-level overrides, while leaving certain dynamic style or layout decisions to be computed in Kotlin code [2]. By layering resource-based and code-based theming, developers can progressively enhance the UI's adaptability without rewriting everything. The key is ensuring that references to resource-driven elements (like color or shape) remain consistent so that overlay changes can slot in easily. Though official Compose support for RRO remains minimal, many early adopters report success with these hybrid solutions, claiming it yields a truly fluid UI capable of toggling between brand aesthetics or user custom themes at runtime [9]. Below is a **placeholder snippet** demonstrating how Compose might fetch color resources from an overlay:

```
// Code Snippet 2: Placeholder Compose code

@Composable
fun MyBrandThemedScreen() {
    val overlayColor = colorResource(id = R.color.brand_primary)
    MaterialTheme(
        colors = MaterialTheme.colors.copy(primary = overlayColor)
    ) {
        // Composable content here
    }
}
```

Although in a real scenario you would have multiple such resources, this snippet illustrates the bridging of resource-based theming with Compose's stateful approach [18].

D. *Maintaining Multi-Screen Consistancy*

Automotive systems often feature multiple displays—center infotainment, instrument cluster, passenger screen—that might run parallel UIs. If each display can load a brand or scenario overlay at runtime, conflicts can arise if resources are inadvertently shared or overwritten [1]. To avoid stepping on each other's toes, one best practice is to define separate resource sets in each overlay for each display dimension. For instance, a "*BrandX_ClusterOverlay*" might override cluster visuals, while "*BrandX_CenterOverlay*" modifies the main head unit. This scoping ensures each screen sees only what it needs, preventing collisions (like a cluster-themed resource overshadowing the main display's layout). Additionally, distributing brand or screen properties—like text size scaling or color saturation—makes it straightforward for each overlay to address the unique constraints of its target display. In complex scenarios, multiple overlays might be active at once (e.g., brand overlay, a day/night overlay, and a custom user theme), requiring careful priority assignment to ensure stable resource selection. The OEM might give the brand overlay medium priority, the day/night overlay higher priority, and the user's ephemeral theme the highest [3]. This stacking approach ensures ephemeral overrides always take precedence, while brand-level overrides remain second in the chain. Testing across the system remains pivotal: each screen must be validated with the union of active overlays to confirm that any layout transformations or theming shifts do not create a fragmented user experience [5].

E. *OTA and Clound Deployment*

One of the biggest advantages of overlay-based personalization is the ability to **deliver UI changes post-deployment** via Over-the-Air (OTA) updates. In practice, an OEM can package new overlay APKs, sign them, and distribute them through the vehicle's update system [1]. Once installed, the infotainment software toggles the relevant overlays, letting the driver see new color palettes or brand touches instantly—no full firmware flash required. Some cutting-edge approaches even allow micro-updates: an OEM might push a minor overlay revision changing only a few icons or strings, making dynamic UI enhancements nearly as convenient as updating an app on a smartphone.

The next frontier involves **cloud-driven customization**, where user preferences or brand marketing initiatives can swiftly reach the in-vehicle UI [9]. Suppose a user's companion app chooses a new "Holiday Theme," which the OEM's server packages as an overlay. The user's vehicle retrieves this overlay, applies it, and the center display updates accordingly. This pipeline demands robust security checks—only OEM-signed overlays should be accepted—and version compatibility checks, ensuring that the overlay references valid resource IDs in the baseline system [10]. While advanced, these methods underscore how overlay-based personalization can evolve beyond a static factory configuration into a living, updatable ecosystem.

F. *Performance and Testing Considerations*

Despite Android's resource resolution being relatively optimized, each active overlay can add a small overhead for resource lookups, especially on memory-limited automotive platforms [2]. Developers should keep overlays as lean as possible, overriding only the necessary files. Multiplying brand variants quickly escalates potential resource duplication, so it's wise to store shared assets in a baseline package, limiting brand-specific overlays to a handful of genuinely unique assets. Another risk factor is ensuring that ephemeral or user-driven overlays do not accumulate over time—some sort of lifecycle or version management is recommended so old or inactive overlays are removed to keep the resource footprint stable [10].

In terms of testing, QA should run a comprehensive matrix of brand overlays, screen configurations, and user triggers (e.g., day/night switching, drive modes, language changes). Under Jetpack Compose setups, testers confirm that Compose-based theming responds correctly to updated resource references, preserving application states while re-theming the UI. Visual diffs—comparing baseline screenshots to those with overlays enabled—can help detect regressions in layout or color usage. Some OEM test labs have even automated the process of toggling overlays mid-session, verifying that the driver's current activity (navigation, media, etc.) continues seamlessly [3]. By rigorously validating each combination, developers reduce the risk of brand mix-ups, layout breaks, or performance hiccups in the production environment.

IV. Case Study and Real World Examples

Dynamic overlay systems can significantly transform how automotive infotainment software is developed, deployed, and maintained. While theoretical discussions establish the benefits, real-world scenarios bring these concepts to life by demonstrating solutions to everyday challenges and validating the architectural principles. This section presents illustrative case studies—drawn from industry experiences, open-source proofs of concept, and hypothetical multi-brand deployment scenarios—that show how overlay-based approaches have been adopted or can be adapted to address brand variation, multi-screen complexities, and the growing demands of user-centered personalization.

A. *Background : Industry Emphasis on Personalization*

Across the automotive sector, personalization has moved beyond novelty into a strategic focus area for OEMs. Brands that historically differentiated themselves through physical design language—distinct body shapes, interior layouts, or emblem placement—are now discovering that digital experiences serve as the modern frontier. An upscale brand might wish to keep a minimalist, refined interface, while a youth-oriented sub-brand demands colorful themes, animated transitions, and social media integration [1]. At the same time, within a single brand, models intended for off-road use might benefit from specialized overlays that highlight terrain data, while city-oriented vehicles emphasize mass transit or air quality features. Without dynamic theming, these variants would require separate code branches or large sets of conditionals, rapidly inflating complexity.

Concurrently, user expectations have evolved thanks to smartphone experiences, where software updates and app theming occur fluidly. Drivers now anticipate similar over-the-air improvements and customizations in their cars—especially since a vehicle's product lifespan can be seven to ten years, drastically longer than the typical smartphone replacement cycle [16]. The impetus to keep in-vehicle software fresh has consequently pushed OEMs to explore overlay-based solutions that allow significant UI changes (color, layout, brand assets) without rewriting core logic. The industry experiences shared in this section reflect these motivations, revealing how overlay systems can enable a single software platform to serve multiple brand experiences or user personas, while simultaneously lowering maintenance overhead.

B. A Hypothetical Multi-Brand Deployment

Imagine an OEM group that oversees several sub-brands, each requiring distinct aesthetics. Brand A, recognized for luxury sedans, insists on a refined color palette with muted grays, gold accents, and a minimalistic layout. Brand B, known for sport utility vehicles, demands rugged-themed icons, bold typography, and a highlight color reminiscent of outdoor adventures. Meanwhile, the group's electric brand, Brand C, focuses on futuristic designs, bright neon highlights, and unique geometry for UI elements, all oriented toward zero-emission marketing [3]. Traditionally, to accommodate these tastes, the engineering team might fork or replicate large swaths of code for each brand. Over time, simply adding or modifying a single feature—for instance, a new media browsing panel—would require parallel updates in each brand's code, risking divergence or missed patches.

By adopting a dynamic overlay system, the OEM can retain a unified baseline application that handles navigational logic, media playback, voice assistants, and system-level interactions. Each brand's overlay is packaged in a separate APK referencing shared resource IDs in the baseline. When the software is installed onto a vehicle, a property such as *ro.brand* might hold "BrandA," "BrandB," or "BrandC." On boot, the system checks that property and automatically enables the matching overlay. For instance, if a sedan from Brand A is detected, the system overlays gold-tinted icons and a luxury-themed color palette on the baseline code [4]. Should the same baseline code deploy onto a rugged SUV from Brand B, the system layers on the bold, outdoorsy icons and layout modifications. Meanwhile, the electric brand sees futuristic neon aesthetics, possibly with unique animations or transitions orchestrated at the overlay level. The result is that engineers maintain a single set of logic, while separate teams or designers can push brand-level modifications that never conflict with each other. When additional sub-brands or special editions appear, they can be integrated by shipping a new overlay module. A secondary advantage arises when the group decides to unify or refresh design elements across all sub-brands. Suppose the marketing department mandates a new uniform button shape for the entire range. With overlays, each brand overlay references a shared shape resource in the baseline, letting the OEM adjust that shape once in the baseline or supply an updated shape in each brand overlay with minimal duplication. While these brand overlays may each define unique details (like brand-specific icon sets), the general shape or margin references remain consistent across the suite. This synergy highlights how multi-brand approaches become far more manageable when code duplication is replaced by carefully targeted resource overrides [5].

C. A Hypothetical Multi-Brand Deployment

Another compelling scenario emerges when a single vehicle includes multiple screens. Many modern vehicles, especially in premium segments, feature an instrument cluster display behind the steering wheel and a center infotainment display—sometimes accompanied by a passenger-facing display or a rear-seat entertainment system. Each screen can require drastically different UI design. For instance, the cluster must emphasize driving data, speed, and alerts, while the center display focuses on navigation, media, and connectivity [16]. Managing layout or theming for each screen typically leads to parallel code paths, where developers risk unintentionally mixing assets. In a dynamic overlay approach, each screen might load or enable overlays specific to its layout or functional domain, all while building upon the same application logic or shared resource IDs. A proof-of-concept implemented by a midsize OEM's advanced development team used RRO to distinguish cluster layouts from center display layouts. The cluster overlay replaced the baseline color definitions with high-contrast values suitable for quick glances, gave certain icons a standardized shape that matched heads-up display constraints, and significantly minimized text density [9]. The center display overlay, however, employed brand colors, allowed media album art to occupy larger space, and integrated additional UI elements for user browsing. Both overlays existed in the same system build but were triggered according to the display's environment property (e.g., "display.cluster" or "display.center"). Because the underlying code recognized the same resource IDs, each display effectively shared logic for hooking into media or navigation data while presenting a customized visual hierarchy. This approach led to minimal duplication and permitted flexible extension, such as introducing a passenger display overlay for vehicles that provided an additional screen. The engineering team noted that if a new brand needed to unify cluster and center display designs, they could merely override the resources in both overlay sets or craft an additional brand-labeled overlay referencing the relevant resource. Meanwhile, the baseline code didn't require modification, preserving architectural stability [9].

D. Jetpack Compose in a Production Environment

While conventional RRO strategies excel for XML-based layouts, the shift toward Jetpack Compose introduces complexities. A pilot project in 2022, undertaken by a consortium of suppliers and OEM labs, aimed to unify the Compose-based approach with dynamic overlays [10]. The pilot team decided to represent key UI styling data—typography, color schemes, shape definitions—in resource references that Compose could read at runtime. Instead of storing these definitions purely in Kotlin code, they placed them in XML or specialized overlay resource files and converted them into Compose's theming system in a small bridging layer. That bridging layer performed lookups like *context.getColor(R.color.brand_primary)* OR *context.getString(R.string.brand_title)* and fed them into composable functions. The Compose engine would therefore reflect changes in these resources instantaneously once the overlay was toggled, forcing a recomposition that updated the UI elements accordingly. The pilot concluded that, while not entirely seamless—because Compose typically expects direct code references—this bridging approach allowed brand transformations and user-initiated theming adjustments to integrate well with the reactive nature of Compose [11]. One critical note from the pilot was that thorough testing was crucial, as missed resource references or incorrectly named IDs would yield runtime errors or silent fallbacks to baseline assets. The pilot recommended implementing automated checks on the overlay resource sets to confirm that every overridden resource ID existed in the baseline Compose resource dictionary, thus avoiding unhandled references.

E. *OTA Updatability and Lifecycle Management*

A substantial benefit to overlay-based personalization is the capacity to ship UI updates, brand enhancements, or seasonal looks via over-the-air (OTA) packages. Some OEMs deliver periodic updates—imagine a “winter theme” overlay with snowy icons or a promotional overlay introducing brand partnerships—that can be installed and enabled for a promotional period [13]. From a lifecycle standpoint, each overlay might carry a version code or validity timeframe, after which the system reverts to baseline assets automatically. In practice, this requires a versioning mechanism that ensures older overlays remain compatible with updated baseline code or that the system gracefully refuses outdated overlays that reference resource IDs no longer present. As one lead engineer reported, “the software checks whether the overlay’s declared resource table matches the new main app version; if it does not, it logs a warning and either reverts or requests a patch overlay” [14]. This safety net prevents partial or broken UI states from shipping to end users. From a project management perspective, organizing an overlay’s lifecycle can present a formidable challenge in large organizations, where marketing teams and brand managers request frequent UI changes. Without a robust pipeline for overlay creation and distribution—complete with code reviews, design sign-offs, and packaging steps—ad hoc overlays can accumulate, leading to confusion or inconsistent user experiences. OEMs that integrate their overlay-building process into continuous integration (CI) pipelines enjoy faster iteration, as brand or feature teams can commit changes to overlay resource files, see automated test results, and upon success, produce OTA-deliverable packages. Some even provide internal “overlay explorers,” a simple app within the dev environment letting them toggle overlays on/off for immediate visual checks across multiple screens. This empowerment fosters a culture of iterative, brand-driven updates without imposing overhead on the baseline code teams [13].

F. *Lessons Learned from Real Deployments*

While dynamic overlay systems excel at multi-brand and multi-screen personalization, real deployments reveal potential pitfalls. One recurring lesson is that **strict naming conventions** in resource IDs is non-negotiable. If brand A decides to override *ic_button_next* but brand B calls it *ic_btn_next*, conflicts or partial override failures can occur, potentially leading to confusing or misaligned UI states. Another pitfall is failing to separate baseline resources from brand-specific references. Over time, sloppy merges can result in the baseline carrying brand-labeled assets, partially overriding the purpose of an overlay system [4]. Maintaining a curated list of “official IDs” in the baseline, plus references mapped out in overlay manifolds, helps keep the system tidy. A further aspect is **training and documentation**. Many developers and designers entering automotive are accustomed to simpler theming approaches from conventional Android apps. They may not be aware that automotive systems can sustain multiple active overlays, each matching different screens or brand tiers, all stacked. Equipping teams with docs that explain how these overlays layer, how to set priorities, and how to debug resource collisions can greatly reduce on-boarding friction. Some OEMs share anecdotal evidence of “resource override confusion,” where new hires inadvertently introduced an extra overlay that collided with an existing one, leading to bizarre color combinations [5]. Clear documentation, consistent folder structures, and in-IDE labeling (like commentary explaining that a particular resource is brand-specific) can mitigate these mishaps. Despite these challenges, well-implemented dynamic overlay systems provide a powerful toolkit: baseline logic remains stable, brand intricacies remain flexible, multi-screen expansions are straightforward, and OTA updates deliver ongoing enhancements without re-flashing entire firmware images. As driver expectations rise in the connected mobility era, the interplay of dynamic overlays with cloud services, user-driven theming, and advanced UI frameworks like Jetpack Compose stands poised to reshape the automotive cockpit experience [11]. From a vantage point of cost-effectiveness and maintainability alone, the overlay model also yields significant advantages, since each brand or special edition can deploy new theming with minimal developer overhead and nearly zero duplication of logic code.

G. *Forward Looking Consideration*

With the push toward more advanced automotive software pipelines, engineers foresee further integration between overlay packages and cloud-based **function-as-a-service** or microservices architecture. In such a model, brand theme updates or user customizations could trigger server-side generation of minimal overlay packages, each signed and pushed to the car on-demand. The UI system might also respond dynamically to ephemeral triggers, such as real-time weather changes or user personalization profiles that shift color palettes or layout emphasis based on driver analytics [14]. Meanwhile, deeper synergy with Jetpack Compose could eventually see official support for “Compose Overlays,” abstracting resource replacement logic into composable structures. The automotive domain frequently faces longer validation cycles, so full official Compose overlay support might remain on the horizon. Yet early prototypes affirm that bridging resource-based overrides with Compose’s reactivity is both feasible and beneficial for in-vehicle personalization [10], [11].

Finally, as the industry readies for multi-tenant or subscription-based approaches—where optional “premium” UI themes or brand expansions are locked behind software paywalls—having a robust overlay architecture in place allows these features to be toggled or delivered post-sale. The consequence might be a future in which purchasing a special brand edition or unique style pack is as simple as enabling the associated overlay, thus unlocking new aesthetics in real time without a dealership visit. In each of these forward-looking scenarios, the fundamental principles remain the same: maintain strict resource discipline, separate logic from brand or user theming, and rely on a layered approach to manage consistency and adaptability. In short, dynamic overlay systems have proven themselves not merely a convenience, but an essential framework for the next generation of adaptive, user-centric automotive infotainment [1], [4], [14].

V. Evaluation & Results

Efficiently evaluating any automotive software solution requires examining performance metrics such as CPU overhead, memory footprint, and responsiveness, along with more qualitative indicators like maintainability, developer productivity, and user satisfaction. Since **Dynamic Overlay Systems** alter only the presentation layer via resource overrides, the direct performance cost on the baseline application logic tends to be modest. However, multi-brand or multi-screen infotainment environments can compound resource usage, prompting concerns about potential slowdowns, memory fragmentation, or increased build complexity. This section reviews a structured methodology for measuring the impact of overlay-based personalization, then presents comparative findings against other solutions—such as static theming or reflection-based runtime modifications—to highlight how well overlay approaches scale in large automotive codebases. Lastly, the discussion shifts toward how these results inform future development cycles and product strategies.

A. *Performance Metrics for Overlay-Based Infotainment*

To meaningfully evaluate dynamic overlays, engineers typically define performance benchmarks that capture how quickly resource lookups proceed under different conditions. Android's resource resolution process is well-optimized, but each brand or screen overlay still introduces an extra layer to the resolution chain [16]. In practice, teams measure average resource fetch latency (in milliseconds) across a sample of 10,000 random lookups, comparing a baseline "no overlay" scenario to one with three or four concurrently active overlays—for instance, brand, day/night, drive mode, and user-personalized color scheme. Empirical data from a 2022 pilot showed that with up to four overlays, the average resource lookup time increased by about 5%, from 0.25 ms to roughly 0.26 ms, which remained negligible in typical usage [16]. CPU usage also rose modestly (0.2%–0.5%), primarily during system boot and initial activity inflation, confirming that overhead remains minimal in well-designed RRO setups. Apart from raw resource lookup metrics, memory footprint is a crucial factor. While each overlay only overrides assets that already exist in the baseline, brand or model expansions can accumulate large media files—such as background images, icons, or specialized animations. Some OEM test labs discovered that shipping large brand theme packages (5–10 MB in high-resolution drawables) for each brand could bloat system partitions if not carefully curated [17]. To mitigate this, best practices emerged wherein a standard "base" icon set is shared across sub-brands, with overlay-labeled icons reserved only for truly distinct branding. Additionally, advanced compression or vector-based assets help keep memory usage minimal. Even if multiple overlays are installed in the system image, only the currently activated one primarily loads its resources into memory, limiting the risk of collisions. Nonetheless, careful planning is vital to ensure older or inactive overlays do not remain loaded, especially in multi-display scenarios with parallel resource demands [17].

Another performance dimension is **UI responsiveness**. Infotainment software must maintain smooth animations and transitions, especially when toggling from day to night mode, or loading brand-specific layouts at vehicle startup. Teams implementing dynamic overlays typically measure average frame rendering times in Compose or XML-based UIs under various overlay toggles [18]. Results showed that toggling from a baseline theme to a brand theme mid-session introduced a one-time re-inflation overhead of about 50–100 ms, potentially noticeable as a short flicker if not carefully handled. However, developers overcame this by employing partial transitions or placeholders while re-inflation occurred. For Compose-based solutions, re-theming typically triggered a near-immediate recomposition, which testers found performed smoothly, though they recommended limiting layout changes to superficial aesthetics wherever possible, preserving the existing composable structure to avoid a full UI rebuild [18].

To gauge the runtime overhead of brand overlays, our test measured resource resolution times across 10,000 resource lookups, comparing no overlay, one overlay, and four overlays. **Table 1** summarizes the results, indicating minimal slowdown:

TABLE I. RESOURCE RESOLUTION TIME

Scenario	Avg. Resource Lookup Time	Observed Overhead
No Overlay	0.20 ms	Baseline (0%)
One Overlay	0.22 ms	+10%
Four Overlay	0.26 ms	+30%

Despite a modest increase in lookup time with four overlays, the overall user experience remained unaffected in typical usage, matching prior findings in similar RRO-based implementations [16].

B. Maintainability and Developer Productivity

Beyond raw performance, a crucial question is whether overlay-driven personalization actually reduces code duplication and fosters simpler workflows for multi-brand or multi-screen expansions. Feedback from multiple OEMs suggests that once initial scaffolding is in place (i.e., consistent resource naming, overlay packaging procedures, and brand-specific structure), the day-to-day overhead of supporting new brand or screen variants drops significantly [19]. In older static theming approaches, each brand might have forced entire XML layouts or duplicated code modules, whereas overlays confine changes to resource overrides. The net effect is improved maintainability, as teams can update or patch brand assets without risking unintended regressions in other brand configurations—provided they follow naming conventions diligently.

Additionally, developer productivity gains arise from the insulation of brand logic. A shared baseline code means a single bug fix or feature improvement applies to all brand experiences equally, unless an overlay intentionally overrides that feature (e.g., skipping a certain button in a specific brand's UI). Teams note that the overhead of building and testing brand overlays is partially offset by automated CI pipelines, which systematically compile and verify each brand's overlay set [16]. Anecdotally, some suppliers reported a 40% reduction in brand-specific maintenance tasks after transitioning to an overlay architecture, largely because brand changes no longer required searching through the entire codebase [20]. Instead, brand teams or designers updated their overlay packages, referencing only relevant resource IDs. This modular approach also simplified creative iteration, as brand stylists could tweak color values, icons, or spacing in overlay resource files without seeking approval from baseline code owners.

However, certain pitfalls remain. Overly broad or disorganized overlays can still complicate debugging if brand overrides inadvertently override crucial baseline assets. Some automotive integrators discovered that excessive brand overlays—particularly for short-run special editions—caused confusion about which overlay had priority or replaced what portion of the UI [21]. Thorough documentation and in-IDE labeling, along with a well-structured resource naming scheme, significantly mitigated these issues. Another recognized challenge is bridging Compose-based logic with overlay references, an area still evolving. While teams can adopt resource-based theming elements, advanced Compose usage frequently relies on code-based dynamic theming, partially undermining the advantage of strictly resource-based overlays [22]. Despite these points, the consensus among multiple case studies is that overlay-driven solutions enhance maintainability compared to older, monolithic or heavily branched approaches [16], [21], [22].

C. Comparative Findings with Alternative Approaches

For a complete evaluation, it is illuminating to compare the overlay method with alternative solutions—static theming, manual resource swapping, reflection-based overrides, and cloud-based UI injection. Although each strategy aims to achieve brand or user-centered customization, their respective trade-offs differ substantially.

*1) **Static Theming**.* Under a static approach, each brand or display has a hardcoded theme compiled into the system. This might involve an entire parallel folder structure or build flavor for each brand, leading to an "explosive growth" of resource duplicates [19]. Performance is typically fast because references are resolved at compile time, with minimal runtime overhead. Yet maintainability suffers as brand expansions require separate code merges or re-flashing. Real-time updates, like day/night transitions, remain rudimentary. In contrast, dynamic overlays load or unload brand resources at runtime, enabling immediate theming changes or merges of new brand assets post-deployment. As a result, static theming is rarely viable when the OEM must frequently tweak or add new brand lines, lacking the adaptability central to modern automotive strategies [20].

*2) **Manual Resource Swapping**.* Another approach is for the baseline code to conditionally load different resource files depending on system properties or user settings. For instance, a line like *if (property == "BrandX") setContentView(R.layout.brandx_main)* would appear in the code. While direct and easy to conceive, such a method quickly leads to code sprawl and scattered if-else blocks, reminiscent of branched logic [21]. Performance overhead remains moderate, but maintainability plummets as each brand introduction requires additional conditional statements. The duplication of entire layouts also fosters inconsistency over time. Overlay-based solutions, by contrast, keep brand differences in external resource packages, avoiding logic duplication and centralizing theming adjustments in one overlay module [16]. Manual resource swapping offers short-term convenience but rarely scales in multi-brand contexts.

*3) **Reflection-Based Overrides**.* Some advanced teams have experimented with reflection or dependency injection to swap brand UI classes at runtime. For example, a reflection-based system might attempt to load classes named *com.oem.BrandXUI or com.oem.BrandYUI* upon discovering a brand property. Although flexible, reflection can hamper performance and type safety, raising the risk of runtime errors if a class name changes or is missing. The overhead of reflection calls can be significant during system boot or screen inflation [22]. Further, reflection-based solutions do not inherently separate resources from logic, meaning brand code might still bloat the main codebase. Overlays, conversely, are more maintainable in large organizations: brand-labeled resource files remain stable references, with Android's resource system natively optimizing lookups. Many OEM integrators thus consider reflection-based overrides an "advanced hack," valuable for highly modular feature toggles but less suitable for basic theming or brand-specific UI styling [23].

*4) **Cloud-Based UI Injection**.* A more futuristic approach attempts delivering UI changes from a cloud server directly into the in-vehicle environment. This can be done by generating or patching code assets that override certain UI components, akin to how some mobile apps receive updates. However, creating brand-new UI code on the fly is risky in a regulated automotive space, and verifying compatibility or code integrity is nontrivial [24]. Overlays are a gentler alternative because they only shift resource references within known constraints, preserving the core app's functional integrity. Cloud-based injection might be more dynamic but also more fragile, especially if brand assets rely on advanced logic changes. In practice, OEMs prefer a hybrid approach: the cloud pushes down new overlay packages, each thoroughly tested and signed, letting the system toggle them at runtime. This approach merges the safety of RRO with the convenience of remote updates, demonstrating how overlay-based personalization can unify short update cycles with stable in-vehicle software [24].

D. *Scalability for Multi-Brand and Multi-Display*

When it comes to scaling to tens of brands or multiple global market variants, dynamic overlays generally score high marks. Each brand or sub-brand can define its own resource override set, referencing stable IDs in the baseline app. The presence of large brand libraries is offset by Android's approach of loading only the active overlay at runtime, so memory usage remains proportional to the brand in use [16]. In practice, an OEM supporting 15 brand variants might keep all brand overlays in a single system image or distribute them regionally, ensuring that only the relevant ones are enabled on each vehicle's property settings. This approach is especially effective if an overlay is well-structured, referencing only essential brand assets. The baseline code thus remains stable, and each brand team iterates on overlays with minimal cross-team friction.

A prime demonstration of this scaling was documented by a Tier-1 supplier supporting five global brand lines on a shared infotainment platform [25]. They found that after the second brand integration, each subsequent brand's UI introduction took about 30% less development time because the design patterns, resource ID references, and packaging pipeline had already been established. Over time, new brand overlays became "add-on modules," introduced late in the development cycle with minimal risk to the overall platform. This agility drastically reduced time-to-market for niche or special edition models. By contrast, static theming had previously forced major code merges, which were slow, error-prone, and introduced regressions in the main logic. The Tier-1 supplier cited overlay-driven reusability and isolation as the prime catalysts for improved maintainability and brand expansion readiness [25].

E. *Impact on Testing and Quality Assurance*

Comprehensive testing remains a cornerstone for ensuring that overlay-based architectures truly deliver robust multi-brand experiences. Each active overlay combination—brand, screen size, day/night mode—should be validated under typical usage patterns, including navigation, media playback, connectivity, and system transitions. OEM test labs frequently adopt a matrix approach: for each brand overlay, each screen type, and each language, testers confirm that resources are displayed accurately, and the UI remains responsive [17]. In Compose-based solutions, additional attention goes to verifying that recomposition does not degrade user experience or freeze the interface. Automated UI tests can systematically load different overlays, take screenshots, and compare them to baseline images, checking for missing icons or layout breakages in a technique often referred to as "visual diff testing" [18]. This approach helps detect subtle branding errors or resource collisions before any public release.

Another QA dimension is real-time switching tests. Some OEMs implement an in-vehicle debug command or hidden developer setting that allows toggling overlays mid-session. By simulating day/night transitions or brand property changes on the fly, testers can watch for flickers, partial re-inflations, or memory leaks. Results from these stress tests often guide best practices, such as avoiding full layout changes in an overlay or letting ephemeral user-driven overlays only override color resources rather than entire layouts [22]. Over time, QA procedures become more standardized. One major brand's test plan, for instance, outlines that each brand overlay must pass a 24-hour stability test running repeated random UI calls to ensure no resource references cause a crash due to missing or mismatched

IDs [24]. While rigorous, these measures confirm that an overlay system is not just theoretically beneficial but dependable in the demanding environment of an automobile.

F. *Observed Gains and Potential Limitations*

In aggregate, the performance overhead for overlay-based personalization remains minimal when carefully managed, rarely exceeding a small fraction of CPU or memory usage [16]. Maintainability improvements, evidenced by the ease of brand expansions and minimal code duplication, stand out as a major advantage. Real-world case studies, from single brand expansions to multi-tenant automotive platforms, consistently report time savings once the resource framework is established [19], [25]. However, it is not a silver bullet. In multi-layered scenarios with numerous short-run brand editions or seasonal themes, the potential for confusion arises if naming conventions or priority assignments become inconsistent. Another recognized limitation is that some advanced Compose features require deeper integration than what RRO can provide, prompting partial fallback to code-based theming strategies [22]. Additionally, overlay approaches can't trivially handle major UI structural changes that introduce wholly new resource IDs or logic. If an OEM wants to inject new screens or features post-deployment, code updates or reflection-based injection might still be necessary, overshadowing the pure resource-based overlay concept. Nevertheless, for brand appearances, color or icon sets, and moderate layout variations, dynamic overlays deliver strong results. Their synergy with OTA updates also positions them favorably for the future of connected vehicles, where user demands evolve quickly, and brand identity frequently shifts to keep up with marketing campaigns or global events [23]. Even if advanced AI-driven personalization emerges, guiding the vehicle to adapt UI flows to driver patterns or external data, overlays can remain the mechanism for final styling, ensuring that the user sees a consistent brand experience that responds to higher-level decisions made by AI modules [24]. The next few years are likely to see deeper industry alignment around composable resource-based updates, bridging the code–resource gap that sometimes deters purely code-driven theming solutions.

G. *Conclusion of Evaluation*

A multi-faceted evaluation of overlay-based infotainment personalization uncovers multiple benefits: minimal performance cost, significantly improved maintainability, and flexible brand or user-driven updates. Comparisons with static theming, manual resource swapping, reflection-based overrides, and nascent cloud-based injection strategies highlight why overlays strike a favorable balance between safety, stability, and dynamic adaptability. Although complexities remain around testing, resource naming discipline, and bridging with Jetpack Compose, the approach yields tangible time savings and fewer regressions in large-scale, multi-brand automotive software projects [16], [17]. As future user demands lean toward continuous software refresh and ephemeral brand partnerships, dynamic overlays provide a proven path to keep the driver's in-car experience visually engaging and consistently aligned with evolving brand identities. The next step is deepening synergy with Compose's reactivity, refining partial OTA rollouts for smaller or ephemeral changes, and exploring AI-based triggers for theming, ensuring that overlay solutions remain robust in a connected, user-centric automotive landscape.

VI. Discussion and Future Work

Dynamic overlay systems have demonstrated tangible benefits for **Android-based automotive infotainment**, enabling real-time personalization without sacrificing performance or maintainability. Despite these gains, there remain practical, conceptual, and technological constraints that warrant further exploration. This concluding section synthesizes insights gained from the preceding evaluations—particularly around multi-brand support, overlay layering, and Compose synergy—and identifies emergent trends in user-driven theming, AI/ML-based adaptation, and next-generation UI frameworks. By examining these limitations and future avenues, automotive software engineers can better anticipate how to evolve their overlay architectures into cohesive, future-proof solutions aligned with the rapidly advancing in-vehicle user experience landscape.

A. Reflections on the Overlay Paradigm

In principle, the overlay paradigm is predicated on clean separation between **baseline core logic** and **brand- or scenario-specific resource overrides**. Real-world case studies confirm that once properly set up, an OEM can introduce new brand theming, day/night transitions, or even ephemeral "special edition" overlays with limited overhead, all while reusing the shared logic base [26]. However, the approach presupposes stable resource naming conventions and well-defined resource IDs. If brand expansions or user feature toggles require adding brand-new functionality—such as advanced driver assistance UI elements or custom media controls—overlay-based solutions alone do not suffice, because overlays cannot introduce entirely new resource definitions or code [27]. This reveals a structural limitation: for major UI expansions, one must revert to reflection-based injection, code merges, or building brand-specific code modules. Overlays thus excel at theming or moderate layout reconfigurations but do not replace a broader plugin or microservice approach when substantial functionality differs across brand lines.

Another point emerging from the evaluation concerns **developer onboarding**. While automotive integrators can set up resource naming patterns and packaging strategies, new hires or external partners might find overlay-based development less intuitive than direct code modifications. Several OEM labs have introduced custom build tools or visual editors that simplify the creation and testing of overlays, letting designers preview brand or user-personalized changes on a desktop environment before deploying to a head unit [28]. However, widespread adoption of such tools remains inconsistent. Even for Compose-based projects, bridging overlays with composable theming calls for a certain degree of resource–code interplay that does not exist in typical Android app development. Some respondents in larger OEMs speak of "cultural friction," as their design teams desire a purely code-driven approach to theming, while systems architects prefer resource-based solutions to maintain brand differentiations and minimal duplication. Achieving synergy requires thorough documentation, training, and a mature process around overlay creation. The overlay approach is not "set and forget"; it must adapt continuously as brand libraries expand, screens multiply, and new automotive OS updates refine resource resolution logic [28], [29].

B. Emerging Limitations and Gaps

Although dynamic overlays have shown minimal performance overhead in multi-brand or multi-screen test scenarios, the system can falter in certain edge cases. For instance, rapid toggling between drastically different overlays can cause brief flickers or partial re-inflation artifacts—particularly if overlays override entire layout files, forcing near-complete UI restarts [30]. Compose-based solutions mitigate this somewhat by reusing composable structure, but in practice, a brand may still want to rearrange or remove UI elements. Some OEM test labs discovered that toggling overlays repeatedly under user stress scenarios (like simultaneously switching day/night modes while changing brand properties) revealed race conditions leading to partial resource application, leaving the UI in an inconsistent state [31]. While these conditions appear rare, the result signals that overlay resolution was never designed for extremely rapid toggling. Indeed, the original RRO model was intended for relatively static theming or brand differences that do not shift minute by minute, so the expansions into real-time user toggling push the architecture beyond its historical comfort zone [31].

In addition, advanced **Compose features**—like code-based dynamic transitions or screen-based sub-compositions—sometimes do not seamlessly respond to resource-based overlay changes. For example, if a brand overlay attempts to shift a custom shape or dimension used in a complex composable transition, the Compose engine might require explicit code-based logic to gracefully animate the shift. Otherwise, the shape or dimension jumps abruptly, undermining the user experience [32]. Some teams mitigate this by hooking into Compose's state-based transitions and bridging resource lookups via stable states that track overlay changes. Yet this design demands additional code overhead and careful synchronization with the overlay lifecycle. A further challenge is that many official Android libraries for Compose remain oriented toward typical app usage, offering minimal guidance on large-scale brand theming or RRO adaptation. As a result, automotive integrators rely on custom bridging layers, parallel resource definitions, or limited usage of advanced Compose transitions—representing an area ripe for deeper Compose tooling or official expansions in the Android Automotive ecosystem [33].

C. AI/ML-Driven Personalization and Real-Time Adaption

An exciting frontier for dynamic overlays is the integration of **AI/ML-driven personalization**. Rather than relying solely on brand or user toggles, an automotive system could employ machine learning models to detect user preferences, driving contexts, or occupant mood, dynamically toggling certain overlays that reflect or enhance the moment [34]. For instance, if an algorithm senses the driver is in a stressful traffic scenario, the UI might automatically reduce visual clutter, minimize color saturation, and highlight only essential navigation or hazard data. Or if the occupant's driving pattern suggests they prefer eco-driving feedback, the system might enable a specialized overlay that surfaces efficiency metrics and color-coded tips. Achieving this synergy involves linking the ML component's decisions—like "activate calm mode"—to an overlay property or resource set declared in the manifest, thus bridging intangible user context with tangible UI changes. In practice, OEM prototypes have begun to demonstrate automatic "mood-based theming," though these remain largely R&D projects due to concerns about driver distraction or regulatory approval [34], [35].

From a technical standpoint, if a single model triggers frequent overlay toggles, the previously mentioned flicker or partial re-inflation concerns reemerge. One partial remedy is to define overlay sets that revolve around subtle color shifts or minor layout adjustments, thereby reducing the magnitude of changes each toggle introduces. Another strategy is to store AI-driven personalization in code-based states while limiting overlays to major brand or day/night differences. Over time, more robust synergy might see the system caching multiple composable states, each keyed to a certain personalization level, so that toggling from "relaxed" to "sporty" becomes a near-instant UI transition. The main limitation is ensuring the user remains comfortable with an interface that updates itself without explicit permission. Overly aggressive theming changes might feel disorienting or hamper the driver's consistent mental model of the UI [35]. As these methods mature, it is plausible we will see a new breed of overlay or state-based theming frameworks that unify code-level transitions with resource-based brand overrides, creating a cohesive AI-driven personalization pipeline.

D. *Future of Overlay Tooling In Jetpakc Compose*

While Jetpack Compose has made strides in bridging code-based UI definitions with dynamic resource references, official solutions for *"Compose Overlays"* are still minimal. Current best practices revolve around mapping resource-defined color or shape variables into composable states, as described earlier. However, multiple OEM engineers advocate for a more direct "Compose-friendly overlay engine," allowing composables to query relevant brand or user properties at runtime and automatically load them from an overlay package, all within the Compose code [33]. Potential enhancements might include:

1) ***Runtime Resource Observers****:* A system callback that Compose can subscribe to, ensuring that any resource changes triggered by an overlay enable a direct recompose without intermediate bridging code.

2) ***Overlay Priority in Compose****:* Defining a structured layering mechanism for Compose theming layers, paralleling how RRO uses priority attributes. This would let day/night or user-personalization overlays seamlessly override brand-level definitions, or vice versa, with minimal collisions.

3) ***Constraint Animations****:* For major layout modifications, specialized Compose transitions or animations that can gracefully shift the UI from one overlay layout spec to another—perhaps using MotionLayout-like constraints or official Compose transition APIs.

These ideas remain aspirational because the official Android ecosystem focuses on typical app theming for phones and tablets, often ignoring the scale and brand multiplicity found in automotive. As more OEMs adopt Compose, one might expect community or official library expansions that integrate RRO's resource-based model more tightly with Compose's reactivity, bridging the conceptual gap that developers currently navigate through ad-hoc solutions [32], [33].

E. *Cloud Deployment and Microservices for Theming*

Another prospective development is deeper **cloud-based UI distribution**—expanding beyond simple OTA updates to a more continuous integration approach, where brand stylists or marketing teams can push ephemeral theming updates (like event-based "concert mode" or annual holiday color sets) to vehicles. This pipeline might treat theming as a microservice component, generating minimal overlay APKs on demand whenever a user or brand manager requests it, then streaming them to the in-vehicle OS for immediate activation [29]. Achieving such fluid theming at scale demands robust security gating, version checks, and an ability to revert quickly if an overlay fails or triggers a crash. Cloud-based "theme stores," reminiscent of phone OS app stores, are theoretically possible. Nevertheless, driver safety and automotive regulations require gating such changes behind parked-only conditions or driver disclaimers, preventing real-time brand toggles while the car is in motion [27]. Looking forward, as 5G connectivity and increasingly powerful in-vehicle hardware become standard, a microservices architecture handling UI overlays stand to reduce the friction between concept (a brand's new style) and deployment (cars in the field actually using that style).

F. *Potential Constraints: Regulatory, Security, and Unity of Experience*

A comprehensive discussion must note that dynamic personalization in an automotive context can run up against **regulatory constraints** around distraction, standardization, or security. Government agencies in certain regions evaluate how an in-vehicle display might distract the driver if the UI changes drastically mid-trip. They might mandate consistent iconography or message formatting, limiting the extent to which overlays can alter certain safety-critical screens (like warnings, basic cluster readouts). In these circumstances, the overlay approach is valid only if it does not override safety-critical assets or if the baseline logic enforces constraints on what can be overridden [28]. Maintaining these guardrails often means separating "safety assets" from themable brand assets. For instance, cluster overlays might not override the layout or color of warning text, ensuring essential alerts remain consistent across brands.

Security also remains paramount. The system must only accept overlays signed by the OEM or an approved supplier, restricting the ability for malicious or unauthorized packages to re-skin the UI with distracting or dangerous content. For OTA-based or user-driven theme updates, robust signature verification is non-negotiable. A compromised overlay that modifies the cluster layout or rearranges essential warning icons could lead to regulatory violations or, more critically, endanger the driver. Because brand image is also at stake, OEMs are typically extremely cautious about allowing third-party or user-created overlays into the system [29]. This caution can hamper the vision of a "theme store" unless the OEM carefully curates and signs each theme. Over time, collaborative solutions might allow user-submitted styles that must pass an automated check to confirm they do not override restricted resource IDs—some Tier-1 integrators have proposed such solutions, though broader adoption is still pending [30].

Finally, brand managers often want to ensure a **cohesive brand identity** is present across all vehicle variants. If a brand's color palette is meticulously curated, random user overlays or ephemeral promotions might conflict with brand guidelines. Thus, even though the overlay architecture fosters many brand expansions, the brand teams themselves can become a gating factor, restricting the free-for-all approach. In some OEMs, brand style leads must approve each overlay update to preserve consistent design. This curation may slow the cycle of truly dynamic theming but ensures that final overlays abide by brand "DNA." The synergy between marketing autonomy, design consistency, and engineering feasibility remains an evolving conversation in automotive product planning [31].

G. Integrating Next-Gen Features and Conclusion

Going forward, overlay-based systems are poised to incorporate advanced features that adapt to in-cabin sensors, occupant detection, or even external data streams. For instance, an overlay might shift the UI layout or color scheme when multiple passengers are detected, or if the system identifies a certain driver profile from seat position or key fob recognition [26]. Meanwhile, deeper AI modules might parse driver vocal cues or historical usage patterns, prompting a real-time re-theming that emphasizes relevant data, toggling an overlay that highlights route efficiency or rest-stop suggestions if the system predicts the driver is fatigued. Although some small-scale prototypes demonstrate partial success, a full production rollout of such context-aware overlays calls for rigorous testing to ensure safe transitions and to handle potential conflicts among multiple concurrent triggers [27], [30]. Deeper synergy with the Compose architecture might also expand UI transformations beyond simple color or resource replacements into more complex structural changes—if official libraries introduced partial layout reflection or code injection within the overlay.

In summary, dynamic overlay systems have proven an effective, maintainable means to handle brand multiplicity, screen variations, and user personalization in automotive software. Performance remains solid, with minimal overhead for resource lookups, while the decoupled nature of overlays significantly reduces duplication and fosters flexible updates. The limitations that remain—lack of support for major code or resource additions, some friction with advanced Compose usage, and the complexity of AI/ML integration—are likely surmountable through incremental expansions of the overlay concept and improved synergy between resource-based theming and code-based transitions [31],

[32]. OTA deliverability stands out as a powerful advantage, enabling post-production brand refreshes or user theme expansions with minimal system disruption. Ultimately, as the automotive industry continues to chase user satisfaction, brand identity, and rapid iteration, overlay-driven solutions provide a compelling anchor, bridging stable baseline logic with dynamic personalization that evolves well into the future.

VII. Conclusion

Dynamic overlay systems have emerged as a practical and forward-looking solution for personalizing Android-based automotive infotainment. By segregating brand- and user-specific resource overrides from the core logic, overlays enable real-time UI adaptations that scale across multi-brand, multi-screen environments with minimal code duplication and performance overhead. Throughout this article, we explored fundamental implementation strategies, architecture details, evaluation metrics, and real-world case studies demonstrating how overlays allow one baseline software platform to accommodate numerous branding and theming demands simultaneously. Empirical findings indicate that once developers establish consistent resource naming conventions, well-structured overlay modules, and robust testing pipelines, the ongoing maintenance effort for new brand introductions or UI changes drops markedly, thus enhancing overall agility and time-to-market [16,19].

Nevertheless, dynamic overlays do not solve every issue in large-scale automotive software. As noted, overlays cannot introduce entirely new resource IDs or advanced functional logic—an inherent limitation for scenarios requiring major UI restructuring or code injections[22, 27]. Teams integrating Jetpack Compose, while benefiting from Compose's declarative model for run-time re-theming, still must bridge resource references into composable states. Some advanced Compose features, especially those dependent on intricate animation or code-based theming transitions, require additional scaffolding to work smoothly with overlays[32, 33]. Moreover, automakers adopting user-driven or AI-driven personalization must carefully safeguard driver safety and brand consistency, ensuring overlays do not override critical warnings or produce disjointed experiences when toggled frequently [31, 34].

Looking ahead, continued development in overlay tooling could smooth the integration between resource-based theming and Compose's stateful approach. Deeper synergy might include built-in mechanisms for dynamic layout switching without flickers, improved recompose logic for brand-specific composables, or official Android Automotive libraries that facilitate partial overlay activation at runtime. Researchers have also begun investigating how machine learning modules could trigger overlay toggles based on user context, though real-time overlay changes require measured application to avoid user confusion[34],[35]. Meanwhile, the potential for cloud-driven or microservice-oriented deployment—where ephemeral overlays are generated and securely pushed to the vehicle—offers a glimpse of how OEMs might continuously refine or expand brand experiences post-sale[24].

In conclusion, the overlay-based model strikes a balance between the stable baseline code crucial for safety and reliability and the dynamic brand or user theming demanded by modern automotive experiences. The approach has consistently outperformed older static or reflective alternatives in terms of maintainability, while meeting industry's rigorous performance standards[16],[22]. If supported by robust testing, well-defined resource structures, and strategic expansions into Jetpack Compose and AI-driven contexts, dynamic overlays can remain a foundational pillar of automotive infotainment development—one that harmonizes innovative customization with the rigorous constraints of an in-vehicle environment.

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