Developing a Multi-User Shared Experience XR Touring System for CSC's #2 HSM Digital Production Line

I-CHUN HUNG*, CHUN-KUEI HUANG*, SHU-AN HE*, CHIE-HSIUNG KUO* and TZU-CHUAN CHAO**

**Green Energy & System Integration Research & Development Department*
*** Rolling Mill Department II*
China Steel Corporation

Tours conducted within the No. 2 Hot Strip Mill (#2HSM) of China Steel Corporation commonly encounter obstacles stemming from high-noise and high-temperature environments, which can potentially impede visitor engagement. This study tackles the challenge by presenting a multi-user, shared experience digital production line tour, exploiting extended reality (XR) and 5G technology. A comprehensive digital environment was designed for the multi-user shared experience (MUSE) XR touring system, merging seven primary zones of #2HSM with 85 OPC production nodes. This configuration provides instant access to live video streams and current production updates, thereby amplifying the richness of the tour experience. The devised system incorporates 13 distinct 3D model sets that accurately mirror manufacturing processes, offering interactive experiences through autonomous, free, and guided modes. Such diversity cultivates a dynamic tour experience, catering to visitor needs of the production process observation. It enables a first-person perspective for visitors, fostering a heightened level of engagement with the manufacturing process. The outcomes of this study are instrumental in fostering visitor engagement during the tour and enhancing their perception of CSC, serving as a catalyst for digital transformation. Future work could focus on improving digital-physical asset integration, propelling the evolution of smart factories towards more sophisticated digital twins.

Keywords: Extended Reality (XR), No. 2 Hot Strip Mill (#2HSM), 5G, Digital Production Line, Real-Time OPC Production Line Information, First-Person Perspective, Digital Transformation

1. INTRODUCTION

Cutting-edge technologies like the Internet of Things (IoT), Artificial Intelligence (AI), big data, and cloud computing are fueling the evolution of smart manufacturing, an area where the fusion of digital and physical elements is a fundamental prerequisite (Tao, Qi, Wang, & Nee, 2019). Distinguished from cyber-physical systems (CPS) focusing on real-time data perception and response, digital twins (DTs) harness high-fidelity digital models of physical entities to simulate behaviors and furnish feedback. This gives rise to a bidirectional dynamic mapping process rendering exhaustive digital traces and synchronized status, enabling rapid and efficient issue detection and forecasting, thereby optimizing manufacturing processes and improving product quality (Parrott & Warshaw, 2017).

In the practical field, organizations like NASA and the U.S. Air Force have adopted DTs for spacecraft and aircraft maintenance and lifecycle forecasts (Negri, Fumagalli, & Macchi, 2017). The employment of DTs has extended to diverse sectors including product design, line design, and smart factories (Tao et al., 2019). Visual aspects in DT systems, such as structures, predominantly depend on 3D models sourced from building information modeling (BIM) (Khajavi, Motlagh, Jaribion, Werner, & Holmström, 2019). With the advent of augmented reality (AR), pre-constructed digital entities can be observed and manipulated. The subsequent development of a wholly immersive environment, extended reality (XR), requires specialized hardware and pre-determined scripts. To attain this, AR/XR systems must adapt the appearance of digital objects relative to the user's position in real-time 3D space (Brito & Stoyanova, 2018). Cultural establishments, such as museums, frequently adopt contemporary digital technologies to enrich visitor interaction with exhibits (Franz, Alnusayri, Malloch, & Reilly, 2019). Museum studies research accentuates the role of shared experiences and social interactions as fundamental factors influencing visitor satisfaction (Packer & Ballantyne, 2005; Pekarik, Doering, & Karns, 1999). These studies underline the potential of digital technologies in crafting more immersive and interactive experiences across various fields.

Industrial site tours at China Steel Corporation's #2HSM offer a significant opportunity for understanding complex manufacturing processes (Figure 1). The #2HSM process involves heating steel slabs and transforming them through several rolling stages to produce hot rolled steel coils. However, these tours frequently expose visitors to strenuous environmental conditions, characterized by excessive noise and elevated temperatures, along with limitations on viewing perspectives. These circumstances can significantly impact the visitor experience and limit their engagement with the tour of the manufacturing process. Visitor experiences during these tours are invariably influenced by a combination of factors. The high noise levels emanate from the movement and collision of steel slabs on the production line, creating an auditory environment that can challenge the ability to concentrate and engage. In addition, steel slabs are heated to exceptionally high temperatures, approximately 1,200ºC. This process results in the emission of substantial radiant heat, manifested as electromagnetic radiation. This heat intensity imposes comfort constraints and potential hazards, further complicating the visitor experience. Lastly, safety considerations dictate strict adherence to established distance restrictions, which often necessitates navigating narrow walking paths, contending with distant views, and coping with limited observation angles. Such conditions cumulatively create an environment that can deter engagement and obstruct the observational capacity of the visitors. These factors can impact the physical comfort of visitors on the tour pathway, especially with larger tour groups where maintaining effective communication becomes challenging for the #2HSM tour (Figure 1). In summary, on-site tour activities can be negatively affected by safety rules limiting active observation, frequent tours increasing personnel pressure, and environmental conditions inhibiting tour effectiveness. This highlights the necessity for innovative solutions to mitigate these physical limitations and boost visitor engagement and understanding during such industrial tours.

When contrasting conventional surveillance camera-based tours with this innovative approach, the limitations of the former become readily apparent. The information overlays provided by the surveillance camera screens are pre-established, inherently restricting the scope of information that can be conveyed. Additionally, the tour viewing angle is strictly confined to the camera's viewing angle. This constraint not only restricts the tour scope but also results in a passive, one-way observational experience for visitors. Such limitations could obstruct the participants' comprehension of the manufacturing processes. In contrast, the deployment of digital production lines offers numerous features that significantly elevate the tour experience. The integration of real-time production line information is feasible, along with flexible on/off and floating block features. Furthermore, this method securely uncovers scenes that are typically unseen or challenging to observe, thereby enriching the experience for participants. It also permits immersive access to the digital environment and encourages direct interaction with the information. Finally, enhancing memory cues through visual information utilization significantly bolsters visitors' comprehension. This addresses the shortcomings of conventional tours. Such an innovative strategy positions digital production lines as a potential solution for enriching visitor experience and comprehension of the #2HSM manufacturing processes.

2. EXPERIMENTAL METHOD

This study delineates the design and deployment of a digital production line leveraging extended reality (XR) technology, thus seamlessly blending digital and physical realms. Capitalizing on the high-speed, low- latency, and expansive connectivity attributes of 5G technology, the exchange of information between digital and physical contexts was amplified. This technological advantage substantially assisted the creation of the multi-user shared experience (MUSE) XR touring system for the #2HSM. In developing this digital

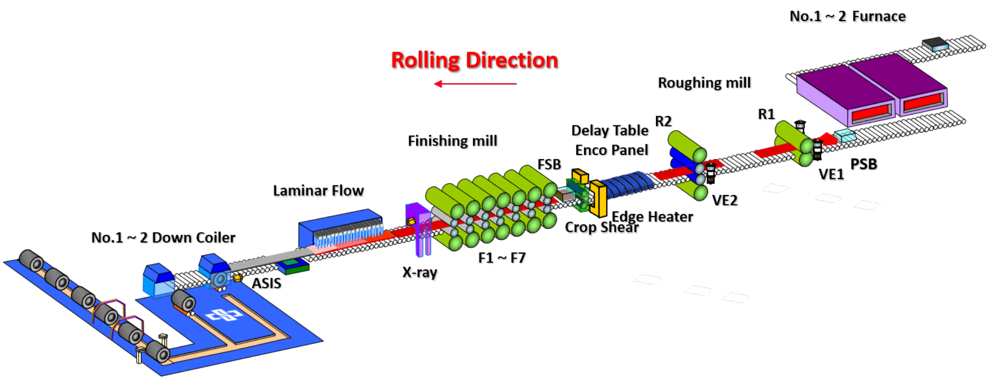

Fig.1. No.2 Hot Strip Mill.

production line, meticulous 3D modeling was employed. Realistic digital models reflecting the actual physical production line were meticulously crafted, leading to a richer, more accurate digital representation. Further enhancing the system, the amalgamation of digital and physical information was ensured through the power of 5G mobile communications. By facilitating rapid and efficient data transfers between the digital and physical environments, a more congruent and immersive touring experience was attained. Lastly, to boost the user experience, an XR multi-user shared experience was integrated. This feature implemented intuitive human-machine interaction, providing an immediate and clear interface for visitors. As a result, the sensory experience during the tour was enriched. This allowed for a more engaging visit and facilitated a comprehensive understanding of the production line process.

In the realm of guided tours, a physical representation of the production line is critical. Therefore, 3D spatial modeling forms the basis for constructing an operational and interactive digital model of the #2HSM digital production line. For efficiency, this study primarily employed optical scanning, supplemented by photographic records to capture the equipment's surface textures (Figure 2).

Upon completion of the 3D models, dynamic production line data were incorporated into the #2HSM digital production line (i.e., the heating furnace, #1 and #2 roughing mills, entry and delivery of the finishing mill, the finishing mill itself, and the down coiler). The comprehensive integration of data, which includes real-time surveillance camera screens, pre-recorded videos from seven primary zones of the production line, and 85 OPC production nodes, provides a thorough and multifaceted illustration of the manufacturing process. This broad array of production line data creates a robust digital representation, enhancing understanding and fostering interactive experiences within the #2HSM digital production line tour.

Leveraging XR technology and user end devices, such as smart glasses or tablets, we project the digital production line onto the corresponding physical spaces in real time. This system ensures rapid synchronization and updates of the digital production line with the current status of the manufacturing process. A shared experience design concurrently allows multiple visitors to access spatial information within the same digital environment, across a variety of devices. (Figure 3). This enables visitors to view the #2HSM digital production line simultaneously from different perspectives in the real world, offering a uniquely personalized experience. Interaction with the digital environment during the tour of the 2HSM digital production line is facilitated by using visitor devices. Compared to traditional industrial tour approaches, the proposed interactive design is to enhance the visitor experience by offering a better understanding of the complex manufacturing process. The utilization of advanced technology allows for an immersive experience that prompts deeper engagement, thereby fostering a richer connection with the tour itself.

The multi-user shared experience (MUSE) XR touring system is characterized by its interactive features, with user interface elements facilitated via HoloLens 2, iPad, and PC devices. The functionalities include perspective shifting, model scaling, translation, rotation, stretching, activation and deactivation of the production line, and switching between real-time or pre-recorded information displays. The MUSE XR touring system offers three distinct touring modes for a comprehensive user experience (Table 1).

Fig.2. #2HSM 3D Spatial Modeling.

Fig.3. The shared experience design by using XR technologies.

Table 1 Three touring modes of the MUSE XR touring system.

Interaction	Descriptions
Autonomous Mode	This mode simulates the entire production line process with a vivid animation, portraying the transformation of a steel slab into a steel coil. The process unfolds across various stages of the production line, with corresponding explanations provided for each key piece of equipment for visitors. This mode caters to the pre-selection of essential information and special effects, optimizing visitors' comprehension of the complex manufacturing processes.
Free Mode	Tailored for individual usage, this mode integrates real-time production line data and allows for a full-scale operation on the digital production line. Visitors can freely interact with the digital environment, offering a flexible and personalized exploration of the #2HSM manufacturing processes.
Guided Mode	Known as the collaborative mode, this interaction allows for a multi-user shared experience. It integrates real-time production line information like the free mode but with the added advantage of synchronous changes. Any alterations made by a visitor are simultaneously reflected in all other visitors' views of the digital production line, fostering a cohesive and collaborative touring experience.

3. RESULTS AND DISCUSSION

A harmonious integration of digital and physical elements was achieved in the successful implementation of the #2HSM digital production line. This was enabled by the incorporation of real-time OPC data nodes and live video streaming. Governing the real-time status of both equipment and steel products, this data was vividly reflected through corresponding animations in the digital platform. Textual representations were used to present static information, such as the ID of the steel coil. Dynamic changes were visually communicated through engaging animations. This included the positioning of steel slabs, transfer bars, or strips within the production line. Color indications were utilized to represent temperature variations, and animations also eflected the physical dimensions. These elements together enhanced the representation of real-time operational changes within the production line. The unity of digital and physical realities was made possible through the innovative use of the XR technology with the smart glasses (HoloLens 2). These cutting-edge tools facilitated a rich and interactive production line experience for users. Interactions were facilitated via intuitive hand gestures, and mobile viewpoints provided users with a flexible vantage point, augmenting their engagement with the production process.

In the MUSE XR touring system, visitors can simultaneously use a range of end-user devices such as smart glasses, tablets, or personal computers to view the same digital production line in real-time (Figure 4 & Figure 5). A specially crafted touring script for docents allows visitors to engage actively in tour activities from a first-person perspective. This grants them the ability to view the real-time status and information of the production line without necessitating physical presence at the #2HSM. The system is also capable of synchronizing all users' actions and the tour guide's perspective, creating a unified, immersive experience (Figure 6).

For example, visitors can engage with the digital production line directly from a comfortable conference room during the tour. They can interact with the digital production line in terms of moving between zones and changing viewpoints they are most interested in. This design offers a safer and less intrusive means for visitors to familiarize themselves with the #2HSM manufacturing

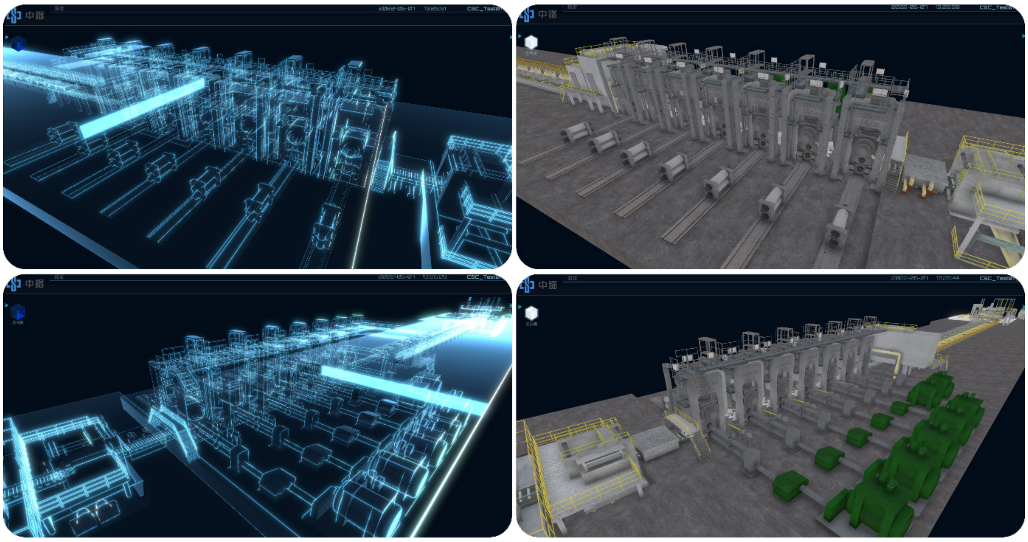

Fig.4. Digital Production Line - Finishing Mill.

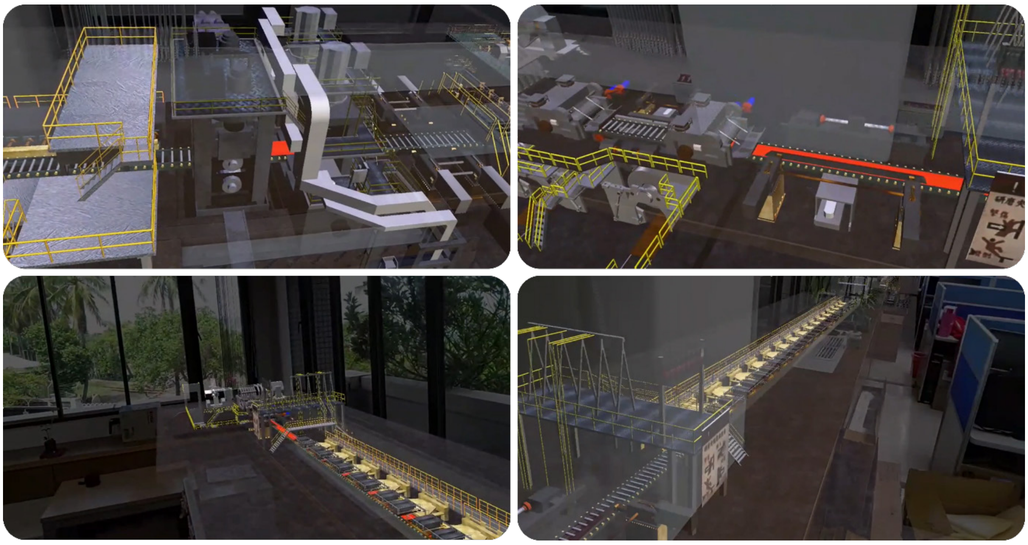

Fig.5. Viewing the digital production line through HoloLens 2.

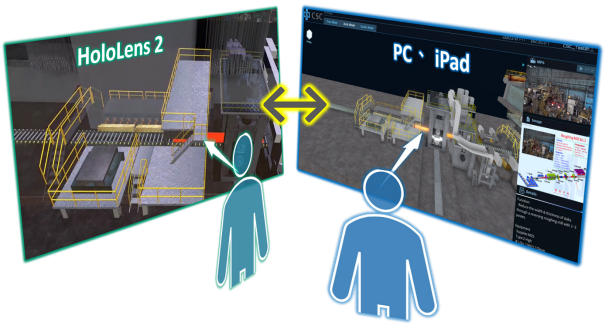

Fig.6. Synchronize the first-person perspective of the docent in between all user devices with the guided mode.

processes, particularly beneficial for those without prior knowledge of it. This digital rendition of the actual operation of the production line effectively simplifies accessibility to complex manufacturing processes (Figure 7).

The foundation of digital twin development rests on the digitalization of physical assets. When possessing a digital representation of a physical asset, real-time data

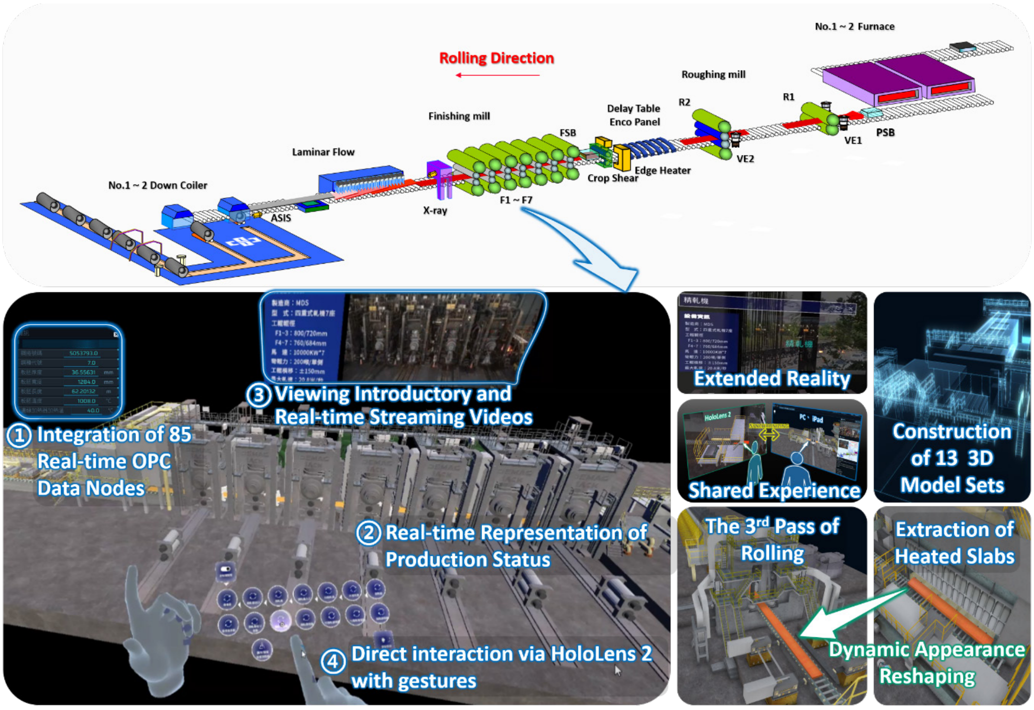

Fig.7. Features of the XR Touring System for CSC's #2HSM Digital Production Line.

integration then can be realized. Given the site conditions at #2HSM, the current tour activities predominantly concentrate on introducing the primary production functions of each zone along the production line. Using the MUSE XR touring system as a springboard for digital twin development facilitates a relatively straightforward integration of digital and physical aspects. It also offers a platform to gather valuable insights into the challenges and best practices associated with modeling a digital twin within an industrial context like the #2HSM.

Three major directions of subsequent development and refinement have emerged from this study. First, a clear focus on specific issues within certain areas could be beneficial. By initially selecting a key zone and concentrating on essential equipment and their manufacturing processes within a small scope, the process of modeling the production line becomes more specific. The transition from physical to digital assets will thus involve a more comprehensive consideration of crucial design factors. Second, the importance of behavior reinforcement through skeleton binding cannot be overstated. The closer the behavior of the digital assets in the modeled digital production line is to the behavior of the physical assets, the more behavioral characteristics need to be considered. These characteristics include forms of interaction between objects, duration, and the physical principles adhered to. Dedicating time and resources to specific objects in the digital production line to increase their skeleton binding numbers will enhance their behavioral performance. Third, strengthening agile modeling feedback is recommended. By shortening the time from the completion of digital production line modeling to animation production, the waiting time for professional members of the physical production line to see the first version of the product is reduced. Even when high-precision modeling modifications are needed, the extended modification time caused by large-scale changes can be mitigated, enhancing the agility of development.

4. CONCLUSIONS

This study utilized the convergence of digital and physical strategy, culminating in a comprehensive digital tour of the #2HSM production line that encompasses seven primary zones. Significant accomplishments and advantages are manifold, including the development of 13 production line models with corresponding behaviors and the establishment of 85 OPC real-time production nodes. Additionally, full control functions of the digital production line and corresponding production animations have been devised for the seven zones. By integrating digital and real-time information, it facilitates the direct observation of live-streaming videos and production statuses within the digital production line. Lastly, preliminary benefits have been gleaned from the digital infrastructure of the MUSE XR touring system. The future evolution of the smart factory can be bolstered by enhancing digital-physical asset integration.

The MUSE XR touring system, applied to CSC's #2HSM, provides a novel intermediary between physical and digital production line tours. Depending on the desired outcomes and visitors' needs, docents can select the adequate approach for conducting a tour. Visitors can view real-time production line statuses and information synchronously and remotely, dedicating more time to enhancing interaction with the docent, fostering a human-centric tour experience, and fortifying the CSC's positive reputation. With the continuous advancements in the completeness, precision, and immediacy of 3D digital models and key production line information, the digital production line is progressively converging with its physical counterpart. This convergence is driven by the enhanced accuracy and real-time availability of 3D digital models, which closely mirror the physical production processes. Consequently, the digital representation of the production line achieves a higher level of comprehensiveness and realism. These advancements in digital technology will contribute to bridging the gap between the digital and physical realms, fostering a more integrated, seamless, and smart manufacturing environment.

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