Virtual Reality Immersion: A Tool for Early Human Factors Intervention

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Widely used virtual reality design review tools provide opportunities for project owners and designers to proactively address safety concerns and avoid expensive re-engineering. This can best be done by involving a human factors professional in the process.

Modern oil and gas processing facilities and refineries are designed using three-dimensional (3D) computer aided techniques. Formal 3D model reviews conducted during the design stage are routinely used to optimize the construction process and facilitate operation and maintenance of the assets. These sessions immerse the design team in the 3D virtual reality environment of the facility and allow the team to view and query the complex geometry and integration of most systems from any perspective. This practice is geared towards identifying and minimizing design deficiencies and conflicts, but it often overlooks how personnel interact with different components and systems, and specifically whether the design has the potential to negatively impact personnel performance.

Some organizations rely upon the experience of the technical review team while other organizations have internal standards that apply to the human factors engineering (HFE) associated with design, construction, or modification of facilities. Human factors include ergonomics, physical capabilities, physical limitations, and behavioral aspects that may be critical to the design of oil and gas units and facilities. Lack of such micro-level considerations may result in human factors deficiencies such as placement of critical valves in inaccessible locations or an increase in occupational injury risks.

3D Model Reviews

The concept of ‘designing the system for operational readiness’ has been identified as one of the 20 elements of process safety by the Center for Chemical Process Safety (CCPS) and has long been applied at the front end of engineering design. A 3D model review is one of the tools used in capital projects, like facility upgrades, such that it not only aids construction but also helps achieve operational readiness and identify potential risks associated with the design of the facility. 3D model reviews are generally conducted in three stages, which reflect the level of readiness of the design:

1. 30% review - conceptual design verification confirms the inclusion of major components and equipment against the piping and instrumentation drawings (P&IDs) and computer-aided design (CAD) drawings, their positioning and spacing, and major electrical components/structures.

2. 60% review - addresses changes resulting from the 30% review and hazard and operability studies (HAZOPs). The goal is to have the detailed design elements in place which will form the basis for construction planning and deliverables including layout of walkways, piping, valves, location of major displays/instrumentation, and electrical routing.

3. 90% review - the final design review to ensure all changes discussed and resulting from 30 and 60% or HAZOP reviews are incorporated. The goal is to get the final design that will be used for construction and training purposes.
These reviews are formal reviews that involve representatives from different disciplines: process engineering, design, process safety, operations, constructions/civil, structural, and maintenance. The inclusion of HFE is necessary in all three review stages, with the goal of identifying and correcting any design issues related to ergonomics and the foreseeable interaction of personnel and equipment. These design issues include, but are not limited to, the following:

- Walkway and egress pathway dimensions
- Location, orientation, and accessibility of valves, equipment, and instruments
- Dimensions and positioning of railings, guards, and toe boards
- Manway sizing, accessibility
- Location of showers and eyewash units
- Design of stairways, ladders, ramps, and platforms
- Equipment and facility labeling, markings, and identification

Some design issues, such as the example of piping routed across a walkway shown in the computer rendering in Figure 1, may seem obvious when taken by themselves. However, the image of the as-built piping in Figure 2 reveals that “the obvious” design deficiencies were not addressed until it was too late.

**Figure 1.** 3D model of a plant section showing piping hindering a walkway (Graphic illustration of an image from OGP Report No. 454, August 2011, p. 26).

**Figure 2.** Image showing the as-built piping hindering a walkway (Source: OGP Report No. 454, August 2011, p. 26).

Applying HFE considerations during the 3D model review stages can help in looking beyond the obvious concerns associated with designs of facilities and systems. Reviewers trained in the field of human factors consider how the five elements of a system (i.e., human, organization, tools/technology, task, and
environment) influence each other and assist the team in identifying design deficiencies due to such interactions. For example, Figure 3 shows a roof section of a 3D model of a cooling subsystem in a process plant. During the discussion about geographic location of the plant, it was recognized that there is a high occurrence of sand storms during the summer months. Because of such environmental impact, the maintenance personnel would occasionally be required to climb up and spray water on the roof to clear up the accumulated sand. By applying HFE expertise, the potential fall hazard was highlighted for this non-routine yet anticipated activity. The identification of the hazard led to consideration of design changes to include fixed stairs and a platform in order to safely access the roof.

![Figure 3. 3D model showing the roof of the cooling unit subsystem without access platforms.](image)

An important HFE consideration is the effect of the location and accessibility of instruments, valves, and displays on personnel. Personnel frequently interact with these elements of the design, and the elements may directly impact an individual worker’s safety or even the safety of the process unit itself. Industry standards can assist reviewers in determining the appropriate location and orientation of different controls and displays, but these may not be readily accessible or understandable to the design team. Figure 4 and Figure 5 depict the preferred configuration of hand-operated valves, based on valve stem orientation. Within this example, HFE may refine the suggested valve configuration based on the local employee base’s anthropometrics, which may differ based on geographic location. As an example, the typical employee in Malaysia will have a shorter median height than one in Norway. Local cultural norms, iconography, and language may also be relevant. By incorporating such HFE expertise, the design may be optimized for general workers or a local population.
Figure 4. Preferred valve location (horizontal stem), ASTM F1166-07 (2013).

Figure 5. Preferred valve location (vertical stem), ASTM F1166-07 (2013).
Not only the orientation of hand-operated valves but also the physical location in a process area is relevant to HFE. For example, valves that are critical for the safety of the system and that require frequent access for operation or routine maintenance should be located at preferred locations for easy access. A valve criticality analysis can be conducted to prioritize valve locations. For example, designers may position non-safety critical valves to a non-preferred but accessible location while positioning safety- or operation-critical valves in a prominent location. Similarly, a task analysis can be conducted to categorize walkways to determine the necessary width of walkways, stairs, and platforms.

Safety is a critical element of the 3D model reviews. Reviewers should identify personnel safety concerns such as trip hazards, head hazards, and blind spots, as part of the 3D model reviews to proactively minimize the potential for occupational injuries. For example, Figure 6 shows a 3D model of a walkway where the stem of a non-critical valve protrudes through the handrail just above the walkway surface. The protrusion is low enough to be easily overlooked by a worker while walking yet high enough to create a trip hazard.

![Figure 6. Valve located as a trip hazard (horizontal stem), ASTM F1166-07 (2013).](image)

In addition to the ergonomics, design, and safety considerations, the review team must also consider the potential foreseeable behaviors that personnel may exhibit in the field. For example, Figure 7 shows valves located on opposite sides of two piping sections. Although there is a crossover platform (not shown in the figure) located several feet down from this location, it can be assumed that personnel may choose to climb over the piping to get to the valves on the other side in an attempt to save time. Such a behavior may pose a safety concern, such as a slip and fall hazard. HFE expertise can help the team identify such foreseeable behaviors and prevent accidents through a design change or possibly communicate the hazard through warning signs.

![Figure 7. 3D model showing location of valves on opposite sides of two piping sections.](image)
The role of human factors engineering in 3D model reviews is critical for proactively identifying and addressing issues that can impact the safe and effective performance of tasks in oil and gas facilities. Review teams should develop and consider strategies that incorporate the human factors and ergonomics principles by including the consideration of anthropometric, strength, and behavioral capabilities and limitations of the personnel involved in the construction, operation, and maintenance of the facility. In addition, review teams should consider the interactions between the different elements of a system and how such interactions may have an influence on the design of the facility such that the potential for human error is reduced to as low as reasonably practicable (ALARP) and the risk of occupational or process-related incidents is minimized.