Design Methodology of Process Layout considering Various Equipment Types for Large-scale Pyroprocessing Facility

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) is designing the Korean Advanced Pyroprocess Facility (KAPF) currently. At present, each item of process equipment required for integrated processing is being examined, based on experience acquired during the Pyropocess Integrated Inactive Demonstration Facility (PRIDE) project [1], and considering the requirements and desired performance enhancement of KAPF as a new facility beyond PRIDE. Essentially, KAPF will be required to handle hazardous materials such as spent nuclear fuel, which must be processed in an isolated and shielded area separate from the operator location. Moreover, an inert-gas atmosphere must be maintained, because of the radiation and deliquescence of the materials. KAPF must also achieve the goal of significantly increased yearly production beyond that of the previous facility; therefore, several parts of the production line must be automated.

This article presents the method considered for the conceptual design of both the production line and the overall layout of the KAPF process equipment. The design approach proposed in this paper can be regarded as an initial step in the design procedure of an integrated process line comprised of equipment with different functions, mechanical structures, feeding mechanisms, and degrees of automation (DOA). The main concepts of this proposed design method are based on constraints that are generally considered in the field of nuclear engineering. On the other hand, a detailed discussion of pyroprocessing is not conducted in this paper, and a detailed understanding of pyroprocessing theory is not required.

We focus on the design methodology employed for a large-scale hot-cell facility, involving analysis of individual items of equipment and causality interfacing for each of these items. The assumptions of this study are as follows:

1. Entire or partial automation of the target facility must be accomplished in order to meet the annual production goal;
2. Handling of each unit process must be performed remotely
3. Gas-tight conditions must be maintained for the main cell, which must be isolated from the operation area;
4. The scale of the target facility is relatively large and the designer must divide the overall cell into smaller cells by optimizing the equipment layout;
5. A station is defined as one of a number of units that comprise the production line. Internally, the station is composed of processers, buffers, and material-handling devices, which move the materials from one processor to another;

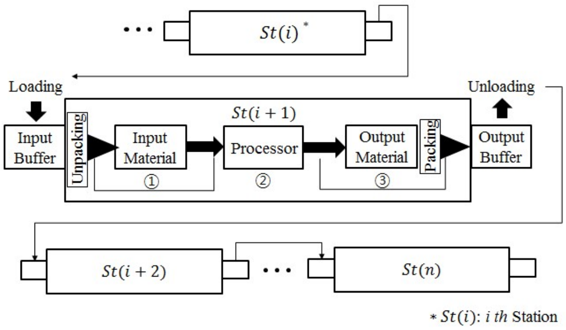


Fig. 1. Station internal structure in KAPF production-line design layout.

6. The DOA of each station is determined based on the automation level of the internal process spanning the unpacking to packing tasks (Fig. 1). Therefore, the intermediate material-handling tasks between the unloading output buffer of the *i*th station (*St*(*i*)) and the loading input buffer of the (*i*+1)th station (*St*(*i* + 1)) are not included in the DOA analysis of each station;
7. All materials must be transported via container, because of the safeguard issues associated with nuclear materials. Therefore, direct transfer of row material as employed in bulk material handling systems is not considered in this study;
8. The meaning of material transfer for the considered facility is limited to the commercial definition, in accordance with industrial standards. Additionally, material flow can be performed via both ground and air, and both continuously and discretely.

A large number of studies have been performed on the appropriate design of process system layouts and material-handling automation for various types of industrial areas. However, this article proposes a production-line design methodology for an exclusive nuclear facility. Those interested in the basic concepts, process simulations and construction plan of the KAPF should refer to previously published studies [1-4].

2. Basic approach to process equipment classification

To contain the various items of material handling-equipment and processors in a unit station, and to properly connect them to the buffers and material-handling devices in the restricted area, we considered a classification method for the target facility in which $x_i(j)$ was defined as $St(i)$ with DOA level j, with $i = 1...n$ and $j = 1, 2, 3$ (n is the total number of stations).

A general process in which row material is supplied, processed, and extracted was considered. During this cycle, the DOA for each process can be classified roughly as follows. First, if the material supply (with unpacking), processing, and extraction (with packing) of a station are automated, that station can be considered to be fully automated (labeled j=3). Second, if any aspect of the supply, extraction, or processing is performed via manual operation at any instant, the station is regarded as semi-automated (i.e., j=2). Finally, if each process must be operated manually throughout the entire station, the station has the lowest DOA (i.e., j=1). Additionally, the following set of parameters was defined to classify the material-handling system candidates. The material-handling method was labeled MH_k, with k indicating AD, AC, GD, or GC, corresponding to a pick-and-place system (discrete delivery), an overhead conveying system (continuous delivery), ground delivery (e.g., an automated guided vehicle (AGV) system, discrete delivery), or a general conveyor system (continuous delivery), respectively.

MH_{AD} can be applied to stations with different processing performance and different feed heights, and to those with a high DOA. MH_{AC} can be applied to cases in which $St(i + 1)$ has sufficiently high performance relative to $St(i)$ to receive the product of $St(i)$ continuously, or where both stations have similar performance at minimum. Likewise, MH_{GD} and MH_{GC} can be applied to station combinations where the $St(i)$ outlet buffer and the $St(i + 1)$ feed inlet have similar heights. Based on the abovementioned assumptions, elevation of the conveyer system transporting the materials was not considered, because the containers must be leveled off during delivery. Note that the selection of MH_k is also based on the product volume.

3. Material-transfer-system combination strategy for production-line design

In the facility considered in this study, various kinds of equipment will be installed and connected. Moreover, the production line and equipment must be operated and repaired remotely. Thus, the material-handling methods that can be utilized under these conditions are restrictive and must be shared systematically between stations. To achieve this, a classification method that allows the required material-handling devices (determined by the selected MH_k) to be assigned to stations based on the station attributes is proposed, as shown in Table I.

Table I: Proposed combinations of transfer and buffer systems based on product volumes.

Flow Direction	Station Buffers and Transfer Type	Transfer System	Loading /Unloading Devices
L to S*	Container distribution buffer (DB) & AD / GD	R: Gantry robot T: Telescopic masts (AD) A: AGV (GD)	R T
S to L	Container stacking buffer (SB), AD/GD, & dumping buffer		
S to S	Container SB & AD/GD		
L to L	Buffer (large container, LB), AC/GC, & LB	CV: Conveyor (GC)	CR: Crane T

* L/S: Large/small-capacity equipment

Additionally, several simple rules were defined for the material transportation in the process line:

1. Single and small containers are delivered directly via AD, from the ith outlet buffer to the $(i + 1)$th inlet buffer;
2. Container bundles are delivered via a ground-based conveyor system;
3. To employ MH_{GD}, an industrial robot or AGV system can be used, provided both the distance between the stations and the containers themselves are relatively small.

4. Case Study

Using the approach described above, we could model the target facilities intuitively. Figs. 2–6 show the design procedures employed for the sample process, based on application of the proposed method. As shown in these figures, the designer can oversee the entire structure of each process node and modify the flow line, so as to group similar stations and to assign the corresponding MH_k efficiently.

The design process of a specified large-scale cell is as follows: (1) The dimensions, mechanical structure, and DOA of each station in the production line are checked; (2) A process diagram is drawn and the individual stations are designed by selecting the transfer means based on the properties of each station, using Table I; (3) Each station is connected according to the predefined causality; (4) The stations are rearranged based on their type of material-handling system, with those using the same type of system being grouped together; (5) The appropriate material-handling system for each group is employed; (6) The cells, including the auxiliary cells and equipment, are designed. These cells can be provided on the same or a different floor, depending on the design policy of the developer.

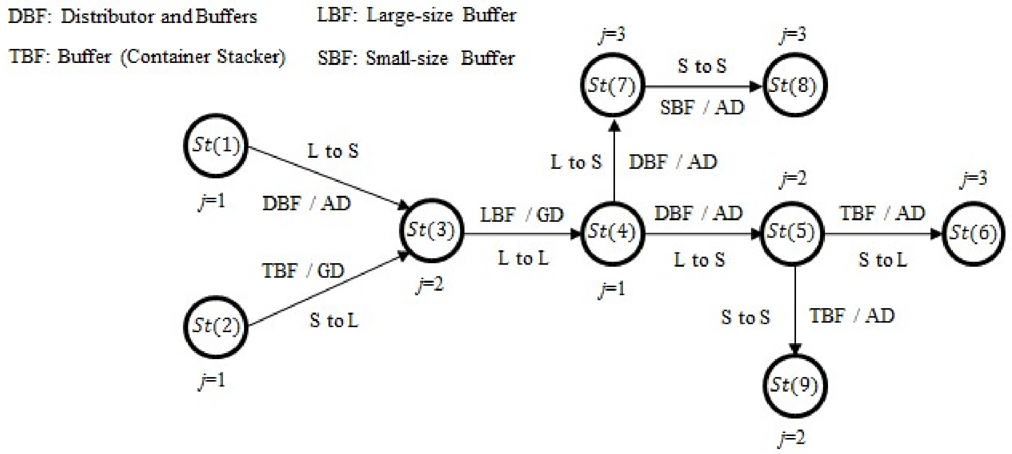


Fig. 2. Example of material-handling flow in chemical processing (1 of 5).
Step 1) The process is simplified; Step 2) The DOA for each station are specified; Step 3) The product volume of each station is surveyed, and the transfer methods from *St*(*i*) to *St*(*i*+1) are selected based on Table I.

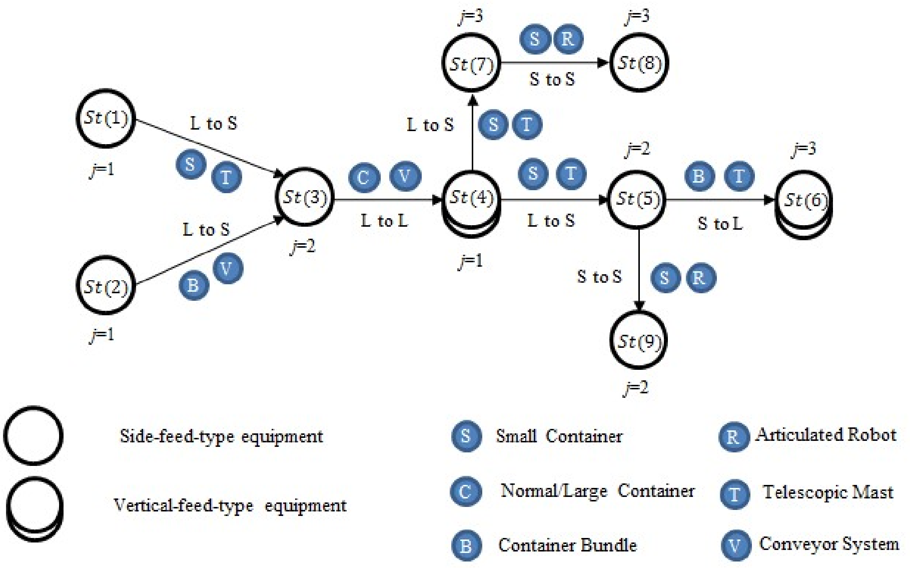


Fig. 3. Example of material-handling flow in chemical processing (2 of 5).
Step 4) The transfer systems from *St*(*i*) to *St*(*i* + 1) are specified based on Table I; Step 5) The feed types of each item of equipment and station are specified.

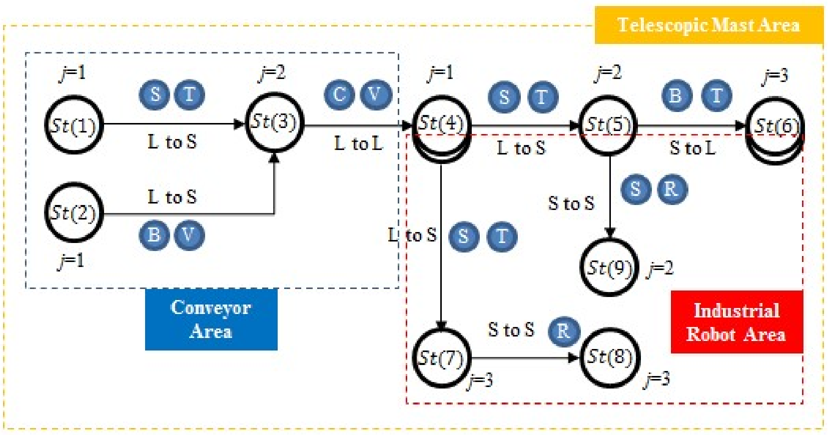
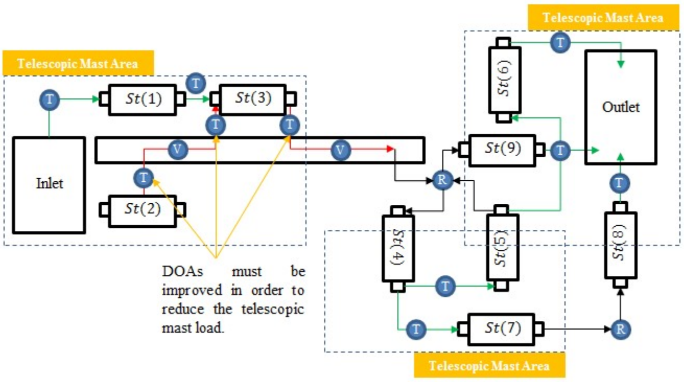
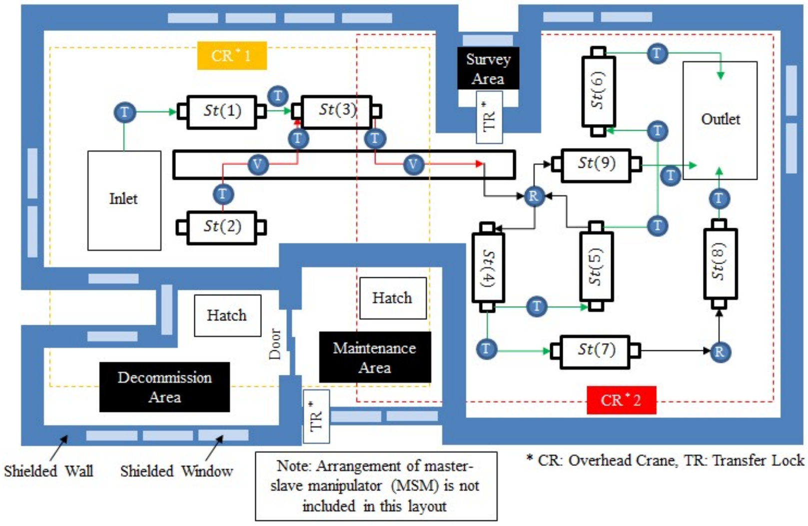


Fig. 4. Example of material-handling flow in chemical processing (3 of 5).
Step 6) The *St*(*i*) are rearranged such that those with the same transfer system type are grouped together, and the working range of each transfer system is defined.



DOAs must be improved in order to reduce the telescopic mast load.

Fig. 5. Example of material-handling flow in chemical processing (4 of 5).
Step 7) The working range of each transfer system is specifically determined and each *St*(*i*) is connected with the applied transfer system in a processing sequence; Step 8) The inlets and outlets are added and the position of each *St*(*i*) is specified, in order to minimize the intermediate material travel distance.



Note: Arrangement of master-slave manipulator (MSM) is not included in this layout

* CR: Overhead Crane, TR: Transfer Lock

Fig. 6. Example of material-handling flow in chemical processing (5 of 5).
Step 9) The boundary of the working area is designed, and the space surrounding the process line is divided into auxiliary rooms; Step 10) The shielded windows are arranged based on the DOA of each station and the essential points of each area.

5. Conclusions

This study has proposed a design methodology that can be utilized as a preliminary step for the design of a hot-cell-type, large-scale facility, in which the various types of processing equipment operated by the remote handling system are integrated. The proposed methodology applies to part of the overall design procedure and contains various weaknesses. However, if the designer is required to maximize the efficiency of the installed material-handling system while considering operation restrictions and maintenance conditions, this kind of design process can accommodate the essential components that must be employed simultaneously in a general hot-cell system.

In future work, the proposed methodology will be improved and applied to a multi-layer facility, incorporating knowledge of large-scale pyroprocessing under hot-cell conditions. The feasibility of the proposed approach will be verified using a digital simulator.

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