Fusion Engineering and Design 88 (2013) 2062–2066

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Logistics management for storing multiple cask plug and remote handling systems in ITER

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HIGHLIGHTS

- We model the logistics management problem in ITER, taking into account casks of multiple typologies.
- We propose a method to determine the best position of the casks inside a given storage area.
- Our method obtains the sequence of operations required to retrieve or store an arbitrary cask, given its storage place.
- We illustrate our method with simulation results in an example scenario.

ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form 7 February 2013
Accepted 8 February 2013
Available online 24 March 2013

Keywords:
ITER
Remote handling
Cask and Plug Remote Handling System
Logistics
Storage location assignment

ABSTRACT

During operation, maintenance inside the reactor building at ITER (International Thermonuclear Experimental Reactor) has to be performed by remote handling, due to the presence of activated materials. Maintenance operations involve the transportation and storage of large, heavyweight casks from and to the tokamak building. The transportation is carried out by autonomous vehicles that lift and move beneath these casks. The storage of these casks face several challenges, since (1) the cask storage area is limited in space, and (2) all casks have to be accessible for transportation by the vehicles. In particular, casks in the storage area may block other casks, so that the former has to be moved to a temporary position to give way to the latter. This paper addresses the challenge of managing the logistics of cask storage, where casks may have different typologies. In particular, we propose an approach to (1) determine the best position of the casks inside the storage area, and to (2) obtain the sequence of operations required to retrieve and store an arbitrary cask from/to a given storage place. A combinatorial optimization approach is used to obtain solutions to both these problems. Simulation results illustrate the application of the proposed method to a simple scenario.

1. Introduction

The ITER (International Thermonuclear Experimental Reactor) is a joint international research project, aiming at the demonstration of the scientific technological feasibility of fusion power as an alternative and safe power source. The Cask and Plug Remote Handling System (CPRHS) provides the means for the remote transfer of (clean/activated/contaminated) in-vessel components and remote handling equipment between the Hot Cell Building (HCB) and the vacuum vessel in Tokamak Building (TB) through dedicated galleries, as illustrated in Fig. 1.

There are different CPRHS configurations, each defined according to the required activity. The largest CPRHS has dimensions 8.5 m × 2.62 m × 3.62 m (length, width, height) and is entrusted with the transportation of heavy (total weight up to 100 tons) and highly activated components [1]. The CPRHS comprises three subsystems: a cask envelope containing the load, a pallet that supports the cask envelope and the Cask Transfer System (CTS). The CTS acts as a mobile robot, provides the mobility for the CPRHS and can be decoupled from the entire system. The kinematic configuration, first proposed in [2], endows it with the required flexibility to navigate autonomously or remotely controlled, in the cluttered environments of the TB and the HCB.

During the reactor's operation, the in-vessel components, such as the blankets that cover the vacuum vessel, are expected to become activated. When such components have to be removed for disposal, operations are to be carried out by the CPRHS, which is required to dock in pre-defined locations, the vacuum vessel

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http://dx.doi.org/10.1016/j.fusengdes.2013.02.036

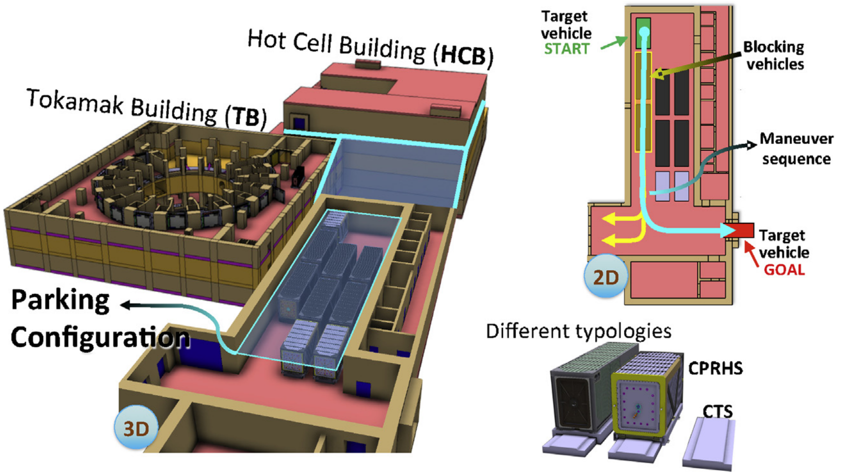

Fig. 1. Illustration of the ITER scenario: from left to right, 3D view of the environment, showing in particular the Hot Cell Building (HCB), the Tokamak Building (TB), and the parking area (PA); 2D view of the cask stored in this area; the different typologies of the Cask and Plug Remote Handling System (CPRHS), together with the Cask Transfer System (CTS).

port cells, located on the three levels of TB: divertor, equatorial and upper level. Then, the components are transported to the HCB for operations of diagnose and refurbishment or disposal of activated material. Hence, the CPRHS must dock at the docking stations through port plugs interfaces or park in parking areas (PAs) at the different levels of the HCB.

This paper addresses the problem of managing the PA for the CPRHS, hereby designated simply by *casks.* We assume the designation of specific PAs. However, given the space constraints in ITER, casks cannot be arbitrarily positioned, since when packing the casks along the available space, casks may block each other. This raises two challenges, that are addressed in this paper: first, since parked casks may block each other, how to retrieve on such blocked casks, and second, since different casks may have differing usage patterns, how to determine the location of each cask, within the PA, such that the most used ones are more easily retrieved. In other words, the first problem can be framed as a planning problem, where blocking casks are moved to temporary positions, in order for the CTS to have access to the target cask. The second problem concerns the optimal arrangement of casks within the PA.

It should be noted that the methods presented here can be applied not only to any ITER scenario (*i.e.*, not limited to the HCB), but also in different application scenarios (*e.g.*, warehouses).

Cask usage falls into two distinct patterns, depending on the type of maintenance operation they are involved: planned and unplanned. For planned operations, cask arrangement can be deterministically ordered so that blocking is minimized. Casks can be re-organized prior to commencing maintenance. However, for unplanned operations, cask usage is unpredictable by nature. Since it is critical to minimize cost losses due to ITER down time, the best one can do is minimizing expected down time, in a probabilistic sense, based on cask usage statistics. If we set the cost of moving casks to the implied ITER downtime, minimizing expected downtime amounts to minimizing expected cost. In this paper we limit our approach to unplanned operations, and thus the criterion being minimized is expected cost of moving the casks.

The problem of determining the best arrangement of items within a storage area is generically designated as *storage location assignment problem* in the Operational Research literature [3,4]. Early work has focused on the research of various assignment policies [5]. More recent research has focused on class-based storage location assignment, employing branch and bound methods [6].

This paper is organized as follows: Section 2 presents the formal problem statement, followed by the proposed solution in Section 3. Experimental results illustrating the approach are presented in Section 4, followed by the conclusions and future work in Section 5.

2. Problem statement

To formulate the problem we start by making a few simplifying assumptions about the scenario. Let us designate *operational area* the space available for both storing and moving casks around.

Our first assumption is that this operational space can be modeled by a graph $\mathcal{K} = \langle \mathcal{X}, \mathcal{E} \rangle$, where $\mathcal{X}$ is a set of nodes, representing physical locations in the environment, and $\mathcal{E}$ is a set of edges, each one denoting a feasible direct navigation path for the CTS between the corresponding pair of nodes (see Fig. 2 for an example [7,8]). Three types of nodes are considered: *stacks* are nodes that allow the storage of one or more casks in line along their length, *crossings* are transit nodes where a CTS can navigate among two arbitrary adjacent nodes, and a special node denoted *exit point*, representing the exit of the work space. Thus, the set of nodes is partitioned into a disjoint union of three subsets, $\mathcal{X} = \mathcal{S} \cup \mathcal{C} \cup \{\varepsilon\}$, where $\mathcal{S}$ and $\mathcal{C}$ are the sets of stacks and crossings, while ε is the exit point. In the example illustrated in Fig. 2, $\mathcal{S} = \{\mathrm{S1}, \mathrm{S2}, \mathrm{S3}, \mathrm{S11}, \mathrm{S12}\}$, $\mathcal{C} = \{\mathrm{A}, \ldots, \mathrm{D}\}$, and $\varepsilon = \mathrm{EXIT}$. Each stack $s \in \mathcal{S}$ is modeled as an ordered set of N_s cells of fixed size (*e.g.*, Fig. 2(c)), say $s = [1, \ldots, N_s]$. Without loss of generality, the leftmost cell 1 of a stack s is the stack exit, *i.e.*, the side where casks enter or leave the stack.

Given two arbitrary stack nodes that are connected in the graph, we assume that there is a feasible trajectory allowing a cask to navigate among these stacks. This trajectory consists in the concatenation of the edges connecting the two stack nodes.

Let $\mathcal{A}$ denote a set of casks. The length of each cask is assumed to be an integer multiple of the cell size. This multiple is denoted L_a, for $a \in \mathcal{A}$.

As its name suggests, storage to and retrieval from a stack of a cask is performed in a Last-In-First-Out (LIFO) fashion. In other words, we have that: (i) only the cask closer to the stack exit is accessible for transportation, and (ii) provided that there is enough free cells adjacent to the stack exit, a newly stored cask will occupy some of these free cells (being the amount equal to the cask size).

Given this model, together with the stated cask movement constraints, we can formulate the logistics problem in the following way:

1. the problem of storing (or retrieving) casks, corresponding to moving a single cask $a \in \mathcal{A}$ from (or to) the exit point ε to (or from) a storage position k within a stack $s \in \mathcal{S}$;