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From battlefield to factory floor: enhancing movable factory deployment planning through military frameworks

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Abstract

Uncertainties in the global market, including supply chain disruptions, local content requirements, and geopolitical conflicts, pose significant risks to manufacturers relying on centralized production systems. Movable factories, mobile manufacturing systems (MMS), and associated frameworks have been proposed in the literature as ways to achieve resilient production networks. However, these deployable manufacturing systems' planning and management aspects remain largely overlooked. This paper explores how manufacturing companies can enhance resilience by adopting military rapid deployment planning principles to deploy production capabilities to geographically dispersed areas swiftly.

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Keywords: Movable factory; mobile manufacturing system; rapid deployment; deployment planning; resilience

1. Introduction

In the present-day global market, uncertainties such as supply chain disruptions, local content requirements, and geopolitical conflicts present significant challenges for manufacturers reliant on centralized production systems. Such events cause disturbances and disruptions in production networks and supply chains, highlighting a need for more resilient production systems that can rapidly recover and minimize downtime while maintaining quality. The concept of movable factories and mobile manufacturing systems (MMS) [1] have been proposed as potential solutions to some of the challenges mentioned above.

2. Movable factories and mobile manufacturing systems

Movable factories encompass many related concepts, but common to all is their emphasis on the spatial or geographical mobility of production assets [1]. This spatial flexibility is enabled by the often more compact and modular design of these manufacturing systems in comparison to their fixed counterparts, which allows them to be installed on trucks [2] or towed by them [3], thereby enabling them to be located much closer to customers [1] and reposition in response to market needs.

Kazemi et al. [1] present a system life-cycle of a movable factory, see Figure 1, which covers several aspects including, but not limited to, procurement, setup, warehousing, and decommissioning. Nevertheless, limited insight into these activities comprising the system life cycle is provided. Nor is any reference given to other sources describing these in detail.

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Earlier research on the life cycles of movable factories likewise indicates essential life cycle steps, yet only limited detail was provided for the comprising activities. Additional information provided concerns relevant considerations regarding MMS configuration [4], maintenance [5], transportation [6], local utilities [4], and work organization during production [7]. It can be argued that the successful operation of a movable factory is significantly affected by how the system should be managed during an operation, which is a lacking aspect in the reviewed studies.

Kazemi et al. [1] provide a significant contribution in reviewing the literature on MMS, and the reader is directed to their recent study for a more comprehensive overview of the literature. Existing research on MMS focuses to a significant degree on facility location optimization (e.g., [8,9]), MMS design (e.g.,[10–12]), or economic evaluation (e.g., [13,14]).

Although limited in number, some case studies from the industry of MMS are available in the literature. Kweon et al. [15] evaluates the profitability of simple mobile bio-mass grinder systems. Likewise, Angioloni et al. [16] are concerned with assessing the financial viability of an MMS, while O'Bryan et al. [3] also analyses the economic feasibility of mobile poultry processing units and the impact of mobile processing units on product quality. Other studies range from presenting life cycle assessments of movable recycling plants [17] to operational performance evaluations, such as measuring the overall equipment effectiveness of mobile explosives manufacturing units in African surface mines [2]. Other studies address optimization issues related to complex and dynamic distributed production networks. Han et al. [9] uses the case of movable farming equipment maintenance units to investigate the optimal placement of these facilities in a production network. Others focus on optimizing transport routes of, e.g., pharmaceutical semi-manufacturers in a production network of movable pharmaceutical factories [18] or routing and capacity allocation problems for mobile bio-diesel factories [19]. Only Yang et al. [20] present the design for an MMS tested in multiple commercial projects. Their case focuses on a movable factory for on-site production of power transmission infrastructure.

While these industrial case studies provide insight into important aspects of MMS and empirically based insights, there is a lack of details or guidance on planning and implementing an MMS in practice – a challenge also highlighted by Kazemi et al. [1].

3. Research question: an analogy to military operations

The U.S. military has – over many decades [21] – built the strategic capability to deploy units to project military force globally [22] within a matter of hours or days from receiving deployment orders [23]. To accomplish such rapid responses to perceived threats requires a proven process for planning and executing such operations and an elaborate process accounting for all relevant aspects that may impact mission performance.

While noticeable differences exist between military operations and manufacturing operations, several similarities are also apparent, e.g., rather than needing to project military force, manufacturing companies may wish to project manufacturing capabilities globally to accommodate some of the market uncertainties introduced in Section 1. Manufacturing companies, like the military, will also want to accomplish this in an expedient manner, which is one of the motivations behind several studies on MMS, as described in Section 2. However, as was also highlighted from the review of related literature, there is a lack of research focusing on the planning process to enable an MMS to respond rapidly and successfully to geographically dispersed emerging risks or opportunities. An initial step towards defining a manufacturing-centric deployment planning process is the identification of relevant design parameters for the process. This research, therefore, seeks to answer the following question:

"How can military deployment planning principles be leveraged to enhance the design of MMS deployment planning processes in a manufacturing context?"

To help in answering this, the following section 4 introduces and describes military deployment frameworks and planning processes, followed by Section 6 which analyses the relevancy of these processes in a manufacturing context before Section 7 then presents a synthesis of these findings into specific suggested design parameters for designing MMS deployment planning processes.

4. The U.S. military's joint deployment framework

The U.S. military's deployment and redeployment process, outlined in ATP JP 3-35 [22], provides a structured approach to rapidly mobilize and relocate forces, as illustrated in Figure , besides the life cycle of a movable factory as defined by Kazemi et al. [1]. Figure illustrates the complete deployment and redeployment process in eight steps. However, five primary phases make up the foundation of deploying or redeploying forces:

1. **Planning**: This phase establishes the strategic objectives, identifies resource requirements, and outlines the movement plan.
2. **Pre-deployment/pre-redeployment activities**: This stage focuses on personnel training, equipment maintenance, and logistical preparations.
3. **Movement**: This phase involves physically transporting personnel, equipment, and materials to the designated location.
4. **Joint Reception, Staging, Onward Movement, and Integration (JRSOI)**: Upon arrival, this phase ensures a smooth transition into operation, including receiving support, establishing infrastructure, and integrating with existing systems.
5. **Employment**: This phase marks the operational use of the deployed forces to achieve the mission objectives.

In the case of redeployment, the process begins from step 5 and loops back to step 1, and similar – but not identical [23] – processes and activities are carried out to prepare the deployed forces to either redeploy to another area of operations or to redeploy to the home station and demobilize.

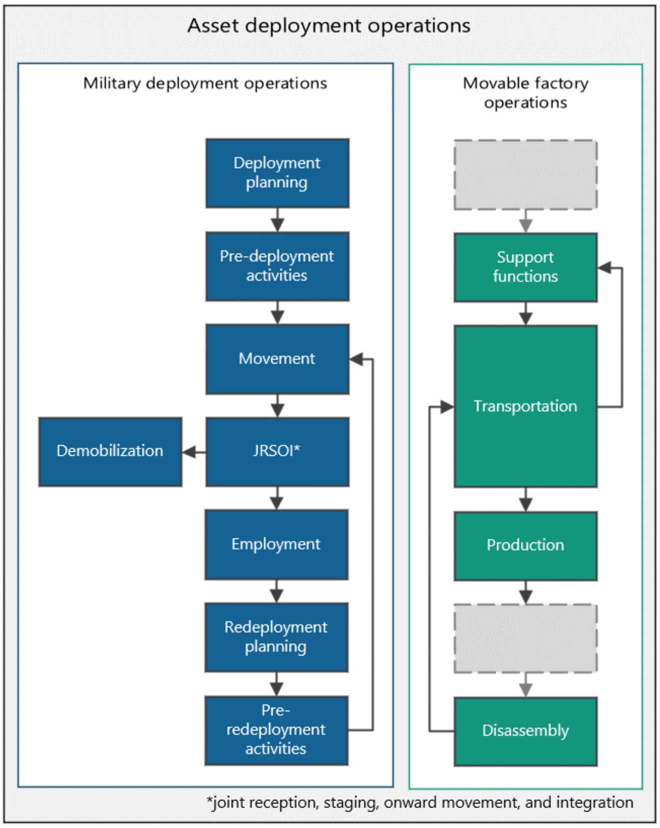

Figure 1: Analogy between operations for the deployment of military forces (adapted from [23]) and movable factories (adapted from [1]), highlighting the lack of planning phases in the latter.

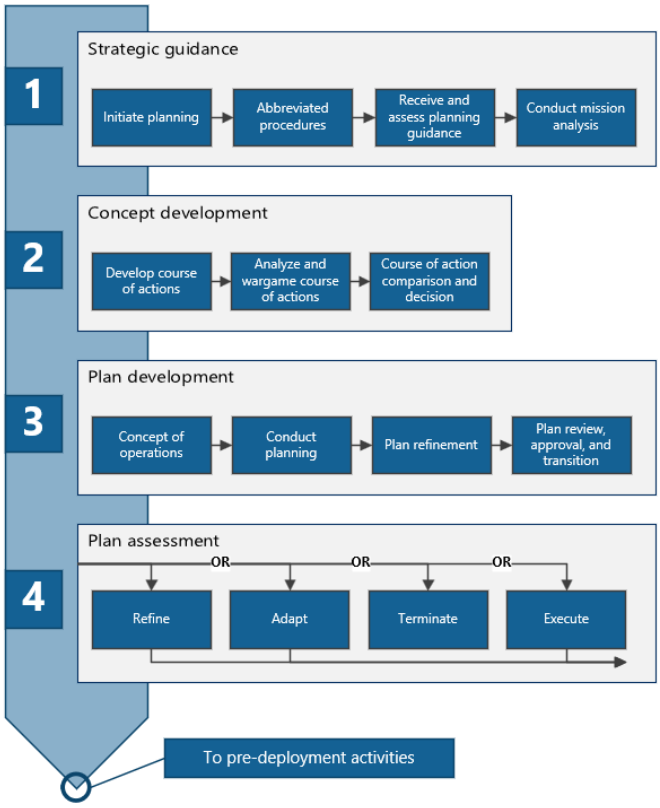

Figure 2: The four major steps and their comprising activities of the U.S. military's joint force deployment and redeployment process planning function.

5. The U.S. military's JFD deployment planning function

This section summarizes the process steps and activities of the planning function of the U.S. military's joint deployment and redeployment process as documented in ATP JP 3-35 [23] shown in Figure 2.

5.1. Strategic guidance

Deployment planning is triggered by identifying a threat that warrants a military response. The time sensitivity of military operations may require expedited processes using a less formalized procedure, which is quickly followed by proper documentation. The planning body receives strategic guidance on deployment strategies and other strategic frameworks. Lastly, mission analysis is concerned with identifying required deployment tasks, resources and capabilities, availability of resources, resource limitations, and command structure for the deployment. The strategic guidance step provides identified tasks, mission limitations, operational approach, planning assumptions, initial resource estimates, and risk assessment.

5.2. Concept development

Deployment concepts are made for each course of action and should include force buildup, sustainment requirements, military/political considerations, and theater-provided equipment (TPE). Courses of action are evaluated against (i) feasibility towards mission accomplishment, (ii) risk and cost in relation to benefits, and (iii) plan completeness. An initial evaluation of the deployment concepts is made using the overall analysis. Afterward, select deployment concepts are subjected to a more detailed analysis involving the simulation of different scenarios through wargaming methods. The focus here is on answering the three evaluation parameters listed earlier, and wargaming can, therefore, be considered a "stress test" of the deployment concepts by identifying, e.g., flawed planning assumptions. Deployment-specific criteria, e.g., timely deployment according to critical mission phases, are then identified to compare the evaluated deployment concepts. The output of the concept development step includes an initial concept of operations, a refined force list, selected courses of action, a time-phased deployment plan, and the commander's estimate.

5.3. Plan development

The concept of operations details the arrangement of sequential and parallel activities needed for mission accomplishment, i.e., activity planning. Three types of planning are conducted: (i) force planning, (ii) support planning, and (iii) deployment/redeployment planning. All three planning functions are conducted iteratively and in parallel to ensure a feasible deployment plan. Force planning refines the type and number of forces needed for mission accomplishment per the refined operations concept. It is essentially the development of a "project plan" for the deployment with time-phased activities and milestones, defined work packages, and procedures. Support planning define and sequence logistics and personnel support per the concept of operations. It involves decisions regarding communications and network support, airfield operations, inventory management, phased delivery plans for mission sustainment, etc. Deployment/redeployment planning should be considered continuously during an operation and typically follow the deployment process in parallel. Individual missions impose constraints on the scope, duration, and scale of deployments and redeployment and, consequently, their planning. Plan refinement analyses the feasibility of plans and identifies shortfalls. Attempts to reconcile shortfalls affecting plan feasibility. Plan refinement is a joint effort between relevant stakeholders. A reviewing body then reviews the plan and communicates the results to the managing body. The plan development step results include a completed deployment plan and a transportation-feasible time-phased deployment plan.

5.4. Plan assessment

The developed deployment plan is then assessed according to its capability to complete the mission, which may result in one of four outcomes: (i) plan refinement, (ii) plan adaptation, (iii) plan termination, or (iv) plan execution. In case of changing operating environments or changes in force, support, or deployment planning, the deployment plan may be refined further. After refinements, the plan may proceed to execution. In case of significant changes in the operating environment or the deployment guidance, the deployment operations plan may require substantial updates to maintain feasibility. If the planning requirement is deemed ill-suited to meet its prescribed objectives effectively, commanders may terminate it, thus simultaneously terminating deployment/redeployment planning activities. Lastly, if the plan is assessed as capable of meeting mission objectives, the deployment plan is executed, marking the formal end of the deployment planning function phase.

5.5. Planning during execution

Deployment planning continues in parallel with the deployment execution, focusing on continuous refinement and implementation of the deployment plan or adapting to changes in the operating environment. Essential aspects of movement planning during execution are the integration of activities and requirements of three types of resources: (i) partial or completely self-deployment capable units, (ii) units requiring lift support, and (iii) transportation of sustainment resources. Although movement planning continues through execution, it provides direct inputs to several execution phases, such as movement, deployment, distribution, and redeployment functions. In situations with limited movement capacity or capabilities, movement priority schemes are developed for assets based on their assessed impact on the mission.

6. Comparing movable factory operations and JFD planning functions

This section analyses the military deployment planning steps and activities illustrated in Figure 2 for their relevance deployment planning of movable factories.

6.1. Strategic guidance

Similar to how the military relies on doctrines as strategic guidance for deployment operations, a manufacturing company could benefit from a movable manufacturing strategy to guide deployment planning. This strategy would outline how the MMS contributes to the company's overall strategy and outline principles and methods for deploying and operating an MMS. Such strategies are likely to be guided by the company's change drivers, such as changes in product variants, production volume, or introducing new products.

Risk assessment is likewise relevant in manufacturing, whether related to change drivers or in general, and the identification and assessment of risks may trigger deployment planning. Although risks are often considered as having negative impacts, they may also represent a potential for positive impacts [24]. An adverse risk, which may trigger deployment planning, includes regulatory changes where an MMS may quickly deploy or redeploy to negate the regulatory impact, such as by deploying closer to customers or to areas less affected by the changed regulations. An example of a risk that may be exploited for positive gains includes market demand fluctuations, which can be capitalized on by rapidly projecting manufacturing capability and capacity to the affected area.

6.2. Concept development

In a manufacturing context, an MMS may not necessarily constitute a complete factory or a self-sustained factory [1], and as such, accounting for TPE may likewise be relevant. This may involve, for example, existing factory buildings or pre-installed production equipment for related manufacturing processes. Integrating mobile production equipment into existing buildings or with existing equipment presents several challenges, e.g., concerning interfaces between these components and integration of these for manufacturing control.

Wargaming in a manufacturing context relates to scenario evaluation. Relevant aspects to consider include Different studies that have addressed the assessment of movable factories from different perspectives (see, e.g., [2,15,16]), yet a comprehensive deployment plan evaluation tool has not been identified.

6.3. Plan development

The time-phased deployment plan is considered relevant in a manufacturing context, and the similarities with traditional project management (e.g., work breakdown and activity scheduling) mean that existing tools may be used to guide this activity, albeit with some context-specific adaptations. In large manufacturing enterprises, it is not unimaginable that multiple deployments might be needed, and as such, the question of allocation priority becomes relevant.

Provides a comprehensive list of supporting functions (finance, facility maintenance, inventory management, materials procurement, etc.), similar to a manufacturing company's support functions. For manufacturing companies, most support functions are expected to remain centrally placed, and support will be provided remotely to the extent possible. Support planning is considered as important, if not more important, than primary asset planning, as a factory without the necessary support network in place will, at best, function sub-optimally and, at worst, be unable to manufacture.

Planning the sustainment of military operations requires procuring consumables such as food, fuel, ammunition, and spare parts. Procuring materials to sustain a manufacturing operation is expected to be more complicated as regional differences in material standards exist. These differences in standards may prove incompatible with product designs or require expensive adaptations.

6.4. Plan assessment

Naturally, as with any other investment in manufacturing, the financial feasibility of a deployment plan in relation to the larger deployment mission must be assessed. Whereas military operations have specific military objectives as their success criteria, deployments in a manufacturing context may have a business strategic objective, e.g., placing a regional factory to circumvent challenges posed by local content requirements or an operational objective tied to fulfilling a customer order by deploying a localized factory at a customer's site.

The ability of a deployment plan to deliver on its success criteria must be assessed before a plan is executed, yet should not be limited to this pre-deployment phase and will be just as relevant during the execution of the deployment plan. Manufacturing companies, like the military, should ensure proper review processes are in place to prohibit infeasible plans from being executed and demonstrate the risk associated with executing deployment plans with poor likelihood of success.

6.5. Planning during execution

While most MMS scenarios likely will not include self-deployable assets, examples of such assets may be mobile construction cranes. Partially self-deployable assets may include the mobile power transmission line manufacturing plant, which can traverse along pre-excavated trenches [11].

A significant difference between the military and most manufacturing companies is the availability of organic lift capability, which is essentially the military's fleet of transport planes. Most manufacturing companies, however, will presumably not have an organic lift capability for their manufacturing assets and will, therefore, most likely rely on contracts with transport suppliers.

As noted earlier, assessment of the developed deployment plan should be done continuously during execution to be aware of the feasibility of continuing with the plan in its present state or whether refinements or more extensive adaptations to the plan should be made – or even if terminating the deployment is the most feasible option.

7. Design parameters for the movable factory deployment planning process

Based on the analysis of U.S. military planning steps and activities and their potential relevance to movable factories and MMS, this section identifies and describes important design parameters for a deployment planning process and discusses the potential application of tools to support these aspects. Table 1 summarizes these design parameters.

Table 1: Identified design parameters for deployment planning processes for movable factories.

Design parameter	Description
MMS strategy	Define how mobile factories contribute to company goals and guide deployment decisions.
Risk assessment framework	Identify and assess risks (negative and positive) triggering deployment planning.
MMS capabilities catalog	Define the capabilities of each mobile unit (production capacity, equipment, integration needs)
Scenario evaluation	Design a tool to assess deployment feasibility for various market situations and resource constraints.
Support infrastructure plan	Develop a plan for providing essential support functions remotely to the deployed mobile factory.
Deployment Prioritization	Establish a framework to prioritize multiple deployment requests.
TPE integration plan	Plan to integrate mobile units with existing facilities and equipment.
Time-phased plan	Develop a detailed timeline for deployment stages.
Planning review framework	Implement a process for continuous assessment of the risk associated with each deployment plan.
Continuous monitoring and adjustment	Continuously monitor the deployment plan during execution, allowing for adjustments to address unforeseen issues.

While Table 1 describes design parameters considered essential for MMS deployment planning processes; other design parameters may be relevant depending on the specific company or industry that forms the MMS context.

8. Discussion

Several potentially relevant aspects of the U.S. deployment and redeployment process have been identified for application in a manufacturing context in Section 6. However, several limitations exist in transferring processes from a military to a manufacturing context. For example, military deployment planners will have to account for the potential presence of mines or booby traps [21] or reinforce deployed buildings to withstand shell fragments or enemy fire [25]. On the other hand, several similarities and relevant considerations have been identified, as demonstrated by the comparative analysis in Section 6. Investigating the extent to which deployment-related planning and management processes are transferable to a manufacturing context will be relevant to practitioners and researchers alike. The same applies to equipment design for rapid deployment scenarios. Here, similarities in approaches can also be identified as demonstrated by, e.g., the use of inflatable tents in the U.S. Army's Force Provider "base kit" [26] – a technology which is also proposed in a manufacturing context by Bataleblu et al. [27] – or the use of a modular and scalable architecture, which is a well-known approach in manufacturing in general, but also within the context of MMS (see, e.g., [10]).

Given the existing literature on movable factories has suggested several tools for aiding manufacturers in several aspects of MMS design and evaluation, further research could be aimed at mapping tools and partial methods to the MMS system life cycle phases and planning process toward building a complete toolbox for practitioners.

Despite the identification of several similarities between military deployment operations and movable factories or manufacturing systems, an inherent limitation of conceptual analysis, as presented in this paper, is the lack of validation of the findings. Case studies presenting insights from manufacturing companies operating movable factories or MMSs would be highly relevant to further this field of research.

9. Conclusion

This research addressed the gap in planning processes for movable factories and mobile manufacturing systems (MMS) by drawing inspiration from the established deployment planning framework of the U.S. military. The analysis revealed significant applicability, with key aspects of military deployment translating to a manufacturing context.

The proposed parameters address MMS strategy, risk assessment, capability cataloging, scenario evaluation, support function infrastructure, and deployment prioritization. These design parameters provide a foundation for developing deployment planning processes and defining key activities. The identified applicability of military frameworks provides a strong foundation for further research into the transferability of military deployment-related experience in manufacturing.

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