Appling Digital Transformation in Intelligent Production Planning of Vietnam's Garment Industry

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Abstract. Currently, the 4.0 industrial revolution is taking place across the globe, and digital transformation is considered a revolution to change how businesses operate and business models fundamentally. In Vietnam, the industrial garment manufacturing sector accounts for 12–16% of the country's total export turnover, accounting for 5.2% of the global market share. This paper presents the digital transformation in industrial garment production using IoT devices to collect production data on sewing lines and methods to digitize the sewing line data industry. After digitizing the sewing line data, the paper proposes an intelligent planning method to improve production efficiency and reduce the time to execute garment contracts. The planning method is based on applying the Real-RCPSP problem combined with the Cuckoo Search algorithm to find a feasible schedule for assigning the resources executing tasks. The experiment results show that the garment contract execution time decreased from 5.97% to 33.99%, depending on the dataset.

Keywords: Digital transformation · industrial garment production management · project scheduling problem · optimization algorithm

1 Introduction

Digital transformation in businesses is taking place firmly, supporting businesses to optimize their production and business processes, improve efficiency, increase profits, and also allow businesses to facilitate negotiations with partners and get more contracts. In industrial garment production, having management information systems (MIS) to monitor production becomes mandatory for big partners to sign economic contracts with enterprises. This is accelerating the digital transformation process in industrial garment production enterprises recently. Many studies have shown the factors affecting the digital transformation of enterprises; with industrial garment enterprises, two factors directly affecting production efficiency are intelligent production planning based on available resources to execute contracts that manufacture and apply the IoT devices for real-time performance monitoring. These factors encourage industrial garment enterprises to transform digitally and develop and exploit information technology applications in their production and business activities.

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The application of information technology in production planning assists transport and transportation operators in maximizing resources and improving the efficiency of production and business activities. To do this work, data on product manufacturing processes, production lines, resources,… Need to be digitized, and optimization problems applied to find a suitable plan for the manufacturing sector. However, data digitization faces many difficulties due to the need for complete descriptions of production data and no effective digital transformation methods, so it can not apply computational models and methods to automatic production planning. Therefore, most production planning is still conducted by experience or manually, leading to many limitations in specific quantitative calculations and allocating labor, resources, and facilities in the field product manufacturing process.

This paper will present digital transformation in enterprises that support monitoring and tracking the efficiency of production work by unit, each production segment over time, and data digitization methods line industrial garment production. After that, it proposes an intelligent production planning method applying the resource-constrained project scheduling problem Real-RCPSP [1, 2]. The Real-RCPSP problem extends the multi-skill resource-constrained project scheduling problem [3, 4], which is applied in a practical production environment. This problem adds a new constraint that presents the execution time of tasks depending on the power of the execution resources.

The following content of the paper includes the following main parts: Sect. 2 presents the research related to digital transformation and the Real-RCPSP problem; Sect. 3 shows the method of integrating IoT devices in industrial garment production and how to digitize data of industrial product production lines; Sect. 4 gives the scheduling problem used in scheduling and coordinating production activities based on the Real-RCPSP limited resource project scheduling problem. Sect. 5 shows the experiment results of the Real-RCPSP problem [1, 2] on actual data collected from TNG company. Section 6 presents conclusions and directions for further research.

2 Related Works

Digital transformation in enterprises and many manufacturing sectors has garnered significant attention and research interest aiming to enhance production efficiency. The researchers have identified factors that influence the success of digital transformation in enterprises. Specifically, Swen and Reinhard [5] highlighted three critical factors affecting the digital transformation process, namely the adoption of new technologies, information technology, and communication in operations, along with the digital competence of leaders. These three key factors are pivotal in enabling successful digital transformation within businesses. Reis et al. [6] classified the significance of digital transformation into three categories: technology, organization, and society. Technology entails using emerging technologies, emphasizing the importance of integrating IoT devices in manufacturing. Vogelsang et al. [7] identified three groups of factors that influence the effectiveness of digital transformation, including organizational aspects (management, employees, data, customers), the business environment (corporate culture, industry characteristics, operational domains), and technology (information technology infrastructure, adoption of new technologies, and information security).

Many researchers have emphasized the role of information technology infrastructure and application strategies that significantly affect the success of enterprises' digital transformation. Osmundsen et al. [8] indicated that one of the eight factors affecting the digital transformation of enterprises is information technology infrastructure; in addition to the readiness for digital transformation, human resources is an essential factor strongly promoted in our research. Marzenna et al. [9] emphasized the impact of information technology on enterprise argumentation, and Muhammad and Anton [10] also analyzed three factors of the digital transformation process affected by the change. New technology changes include adaptability, resource addition, and innovation ability that positively impact the development of digital transformation.

According to the authors' research [11], digital transformation agents in enterprises usually include 5 main factors: leaders, human resources, IT infrastructure, the budget, and services in digital transformation. In particular, the IT infrastructure factor plays a vital role in the success of the digital transformation process of enterprises.

To make intelligent production planning, the authors in the paper [1] stated the project implementation accounting scheduler with limited resources Real-RCPSP, this problem exhibits a highly relevant characteristic in the industrial garment manufacturing sector, as it incorporates constraints on project resource allocation and the scheduling of tasks within a project (in the context of garment production, this refers to the execution of garment contracts). The problem's constraints indicate that higher-skilled resources (workers) can complete tasks in shorter durations or achieve higher quality. This paper will employ the Real-RCPSP and actual production data to coordinate production planning tasks.

3 Integrating IoT Devices and Digitizing Industrial Sewing Data

Digital transformation uses digital technologies to change business models, creating new opportunities, revenue, and value [12]. Digital transformation in enterprises is understood as changing from a traditional model to a digital business by applying new technologies such as big data, the Internet of Things (IoT), and cloud computing to change the way of controlling, managing, leadership, work processes, and corporate culture. It is about rethinking how organizations bring together people, data, and processes to create better new value. Digital transformation is the only consulting restructuring in distributing data, processes, and people that creates new value. In industrial garment production, the digital transformation process is associated with the equipment and integration of IoT devices so that managers can real-time monitoring production progress and plan innovative production to improve work efficiency.

3.1 IoT Devices Integration

One of the factors to improve production efficiency is that managers need to grasp the production progress, which is continuously updated, thereby providing timely management solutions. With the development of technology in the current industrial sewing industry, industrial sewing machines can integrate with IoT devices to collect product information about the production process and the sewing machine's working process. Over time, from which to evaluate the detailed working efficiency of each worker, each machine can also monitor the performance of investment equipment. IoT devices attached to sewing machines have been exploited by some research, production, and development units for sewing lines at enterprises, one of the commonly used devices is the Brother device [13]. The operation procedure of the device is carried out through the steps shown in Fig. 1.

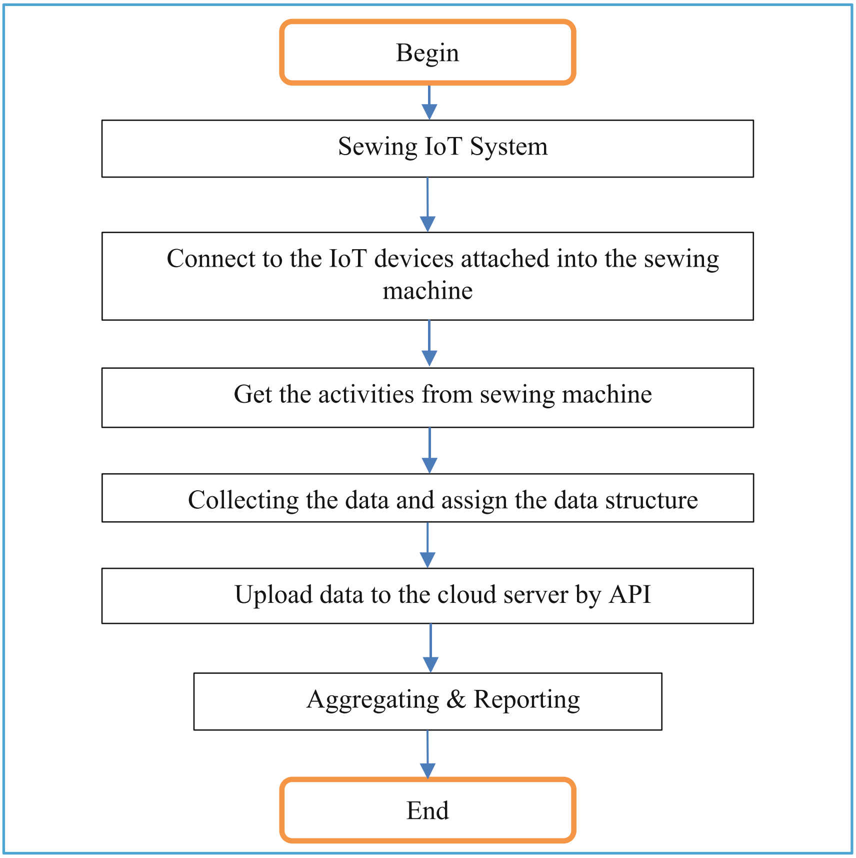

Fig. 1. Steps to collect data from Brother devices

The collected data will be sent to the IoT device provider's cloud server center. The enterprises will monitor via the web application of the IoT device provider system or management information system (MIS) of the companies to synthesize reports according to the enterprise's administrative requirements. Figure 2 tracks the performance of the 21 lines in a garment company on MIS.

The MIS integrates with IoT devices' data by connecting to the data system stored on the IoT device provider's Cloud server. Connecting and retrieving data from Cloud Server is done through the API through the steps shown in Fig. 3 below.

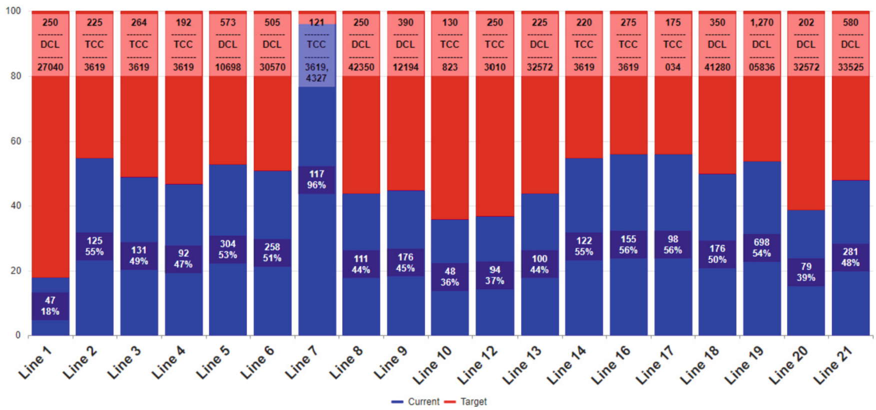

Fig. 2. Productivity chart of a company with 21 sewing lines

3.2 Production Line Data

The production lines usually observe the sequence of stages from input materials at the beginning and create products at the last stage. At each stage, input materials and middle products at different outputs will be used. To complete a production stage, it is necessary to use different resources such as equipment, machinery, raw materials, and labor. In particular, machinery, equipment, and labor resources are often limited to a certain number, and these resources also have different capacities.

Production data typically includes the parameters described in Table 1 below.

3.3 Sewing Line Data

In industrial garments, to complete a contract (with many products of the same type), the company will organize sewing lines to carry out the production stages of the product. Each sewing line has many workers with different skill levels; Sewing stages in a sewing line are arranged in the order of priority of the production process.

Description of sewing line data

For each garment contract, which will be performed on the sewing lines, the manager will make a production plan based on the data: contract, labor, labor qualification, and other related resources. Constraints for planning production on the sewing line are described in Table 2 below.

Based on the characteristics of sewing line data, towards the application of automatic production planning, sewing line data can digitize according to the following rules:

- Each garment contract is one project
- Each stage of the product is a task
- The execution time of a stage is the time to execute a task
- Workers have skill levels from 1 to 7; the level of workers will correspond to the skill level in the Real-RCPSP problem model.
- Each worker is a renewable resource; the resource will have a specific skill level
- The priority of stage is the priority of tasks.

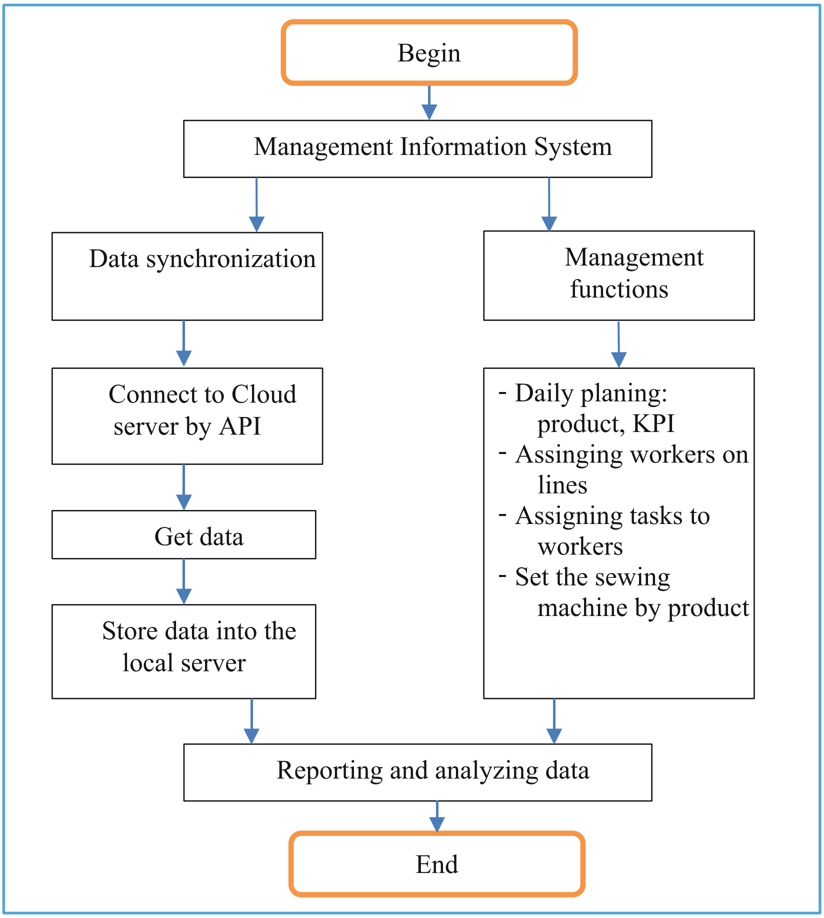

Fig. 3. Data aggregation of IoT devices into MIS

Example 1:

Digitize data on TNG's garment contracts [19] is shown in Table 3 below.

These contracts can be organized by 04 sewing lines with the corresponding number of workers on each line as 37,39,47,41.

Applying the rule of digitizing sewing line data with contract data in Table 3, we get a standard dataset suitable for inputting the Real-RCPSP problem, as shown in Table 4 below.

In Table 4, the column "*Performance Time (PT)*" is the total actual contract execution time in hours.

Table 1. Production data parameters

No	Content
1	Products to be produced
2	Number of products to be produced
3	Number of products in production stage
4	Order of execution of stages
5	Resources needed for each stage
6	Skills (Capability) of Resources
7	Resource type: - Resource Consumption (use one time) - Renewable resources (machinery, labor, etc.)
8	Capability resource requirements for each stage
9	The execution time of each state of work corresponds to different capacities of the resource
10	The costs

Table 2. Constraints for planning on the horizon

No	Constraint
1	Each contract will order one product type
2	Each type of product under the contract will have a different number of stages
3	Each stage will require the worker with the specific level of skill
4	A worker with a higher level of kill can perform better that lower rank
5	The stages have a priority relationship with each other, the previous stage is not finish, the later stage can not be start
6	Based on the contract, the company may assign workers to execute
7	The company setups many lines (team) to run the contract

Table 3. Garment contracts

No	Contract	Product Type	Product number	Number of task
1	WE1190/1698402 Liner Buy Mar 14-F19	T-shirt	33,693	71
2	FM4013/ 1536181 buy 11/11-F19	swimming trunks	83,340	137

Table 4. TNG dataset

Datasets	Tasks	Resources	Precedence Constraints	Number of skills	Performance time (PT)
TNG1	71	37	1026	6	409
TNG2	71	39	1026	6	325
TNG3	71	41	1026	6	296
TNG4	71	45	1026	6	392
TNG5	137	37	1894	6	1174
TNG6	137	39	1894	6	1052
TNG7	137	41	1894	6	871
TNG8	137	45	1894	6	996

4 The Real-RCPSP Problem

The scheduling of projects, economic contracts, or actual production processes is always constrained by requirements such as completion time or resources used. The RCPSP (Resource Constraint Project Scheduling Problem) [14, 15] is a problem that aims to solve the situation schedule for projects with limited resources which is proven to be an NP-Hard class, so it can not find the optimal solution in the polynomial time. By applying the approximate methods to the RCPSP problem, we can find reasonable scheduling solutions that reduce project implementation time and cost. In reality, RCPSP can be applied in many areas of life, such as the economy, military, transportation, and garment industry,… A sub-class extending from the RCSPP problem is the Real-RCPSP problem, added two new constraints as follows:

- A resource can have many different skills; each task will require the execution resource to satisfy the skill requirements at the specific ability.
- A resource whose skill matches the task's requirements and has a higher skill level will be able to perform the task better.

With the addition of 2 new constraints, the Real-RCPSP problem has high applicability in planning and operating production.

The Real-RCPSP problem can be conceptually formulated based on the notations in Table 5.

The Real-RCPSP problem could be state as follow:

$$f(P) \to min \tag{1}$$

where:

$$f(P) = \max_{W_i \in W} \{E_i\} - \min_{W_k \in W} \{B_k\} \tag{2}$$

Table 5. The notations

Symbol	Description
C_i	The set of tasks need to be completed before task i can be executed
S	The set of all resource's skills S^i: the subset of skills owned by the resource i, $S^i \subseteq S$;
S_i	The skill i;
t_j	The duration of task j
L	The resources used to execute tasks of the project
L^k	The subset of the resources which can be performed task k; $L^k \subseteq L$
L_i	The resource i
W	The tasks of the project need to do
W^k	The subset of task which can be executed by the resource k, $W^k \supseteq W$
W_i	The task i
r^i	The subset of the skill required by task i. A resource has the same skill and skill level equal to or greater than the requirement that can be performed
B_k, E_k	The begin time and end time of the task k
${A_{u,v}}^t$	The variable to identify the resource v is running task u at time t; 1: yes, 0: no;
h_i	The skill level i;
g_i	Type of skill i;
m	Makespan of the schedule
P	The feasible solution
P_{all}	The set of all solution
$f(P)$:	The function to calculate the makespan of P solution
n	Task number
z	Resource number

Subject to the following constraints:

- $$S^k \neq \emptyset \ \forall L_k \in L \tag{3}$$
- $$t_{jk} \geq 0 \ \forall W_j \in W, \quad \forall L_k \in L \tag{4}$$
- $$E_j \geq 0 \ \forall W_j \in W \tag{5}$$
- $$E_i \leq E_j - t_j \ \forall W_j \in W, \ j \neq 1, \ W_i \in C_j \tag{6}$$

- $$\forall \text{ W}_i \in W^k \exists S_q \in S^k : g_{S_q} = g_{r_i} \text{ and } h_{S_q} \geq h_{r_i} \tag{7}$$

- $$\forall L_k \in L, \forall q \in m : \sum_{i=1}^{n} A^q_{i,k} \leq 1 \tag{8}$$

- $$\forall W_j \in W \exists !q \in [0, m], !L_k \in L : A^q_{j,k} = 1; \text{ where } A^q_{j,k} \in \{0; 1\} \tag{9}$$

- $$t_{ik} \leq t_{il} vo' ih_k \leq h_l \forall (r^k, r^l) \in \left\{ S^k \times S^l \right\} \tag{10}$$

In the Real-RCPSP problem, each task has additional skill (skill) requirements of the resource needed to perform, each resource is also divided into different skill levels.

5 Appling the Real-RCPSP Problem in Industrial Sewing Production Planning

To plan production coordination in each sewing line, we apply the Real-RCPSP problem with the digitized sewing line datasets shown in Table 5.

Real-RCPSP is a problem of class NP-Hard, which can not be solved in polynomial time, so it is necessary to use some evolutionary algorithms to find the best schedule for each dataset. In this paper, the author applies CS (Cuckoo Search) algorithm [16–18] to find a schedule. The result can be used to make the production coordination plan by assigning the resources to perform the stages of industrial garment production.

The application of the Real-RCPSP problem to the industrial garment production process allows the leaders can build an automatic production plan, without using traditional, manual methods, according to experience. The production plan is automatically generated based on the input datasets (the digitized orders) for the Real-RCPSP problem combined with the CS algorithm. The calculations are made in detail based on constraints of the labor requirements, execution time, and number of products,…

Experimental parameters

The experiment to find a solution using the Real-RPCSP problem and the CS algorithm is performed with the following parameters:

- Dataset: 08 datasets presented in Table 4
- Population size N_p: 70
- Number of generations, N_g: 60,000
- Number of test runs: 20.

Actual environment: Microsoft Visual Studio 2019, C#

Experimental Results

The test run results can be shown in Table 6 below.

Table 6. Experiment results

Datasets	TNG PT	CS	Deviating	%
TNG1	409	270	139	33.99%
TNG2	325	247	78	24.00%
TNG3	296	236	60	20.27%
TNG4	392	260	132	33.67%
TNG5	1174	947	227	19.34%
TNG6	1052	953	99	9.41%
TNG7	871	819	52	5.97%
TNG8	996	861	135	13.55%

In Table 5, column TNG PT is the actual contract performance time (in hours) of TNG company, column CS is the planned execution time (schedule) set by the application of the Real-RCPSP problem model combined with the solution by the CS algorithm.

Table 6 shows that, when applying automatic scheduling by evolutionary methods, it will bring better contract completion time than current practice from 5.97% to 33.99%. The difference in execution time can be done by a tool as shown in the expression in Fig. 4.

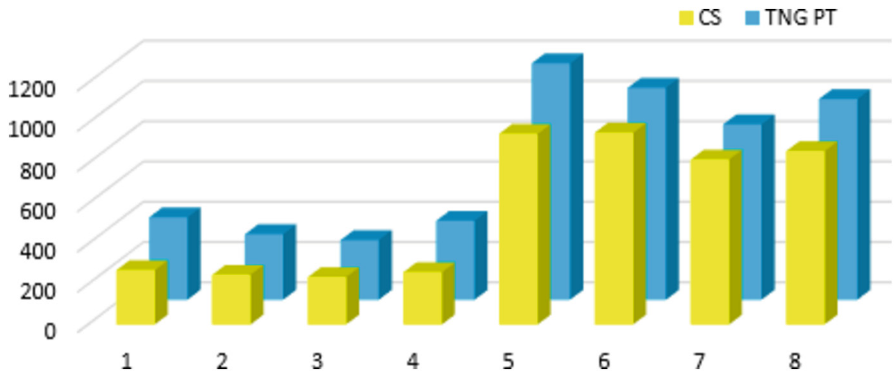

Fig. 4. Comparison of execution time between CS and TNG PT algorithms

The conducting result shows that it is possible to automatically calculate the workflow coordination and the assignment of stages in the industrial sewing line. The industrial sewing data is suitable for the model of the Real-RCPSP problem because the data and process characteristics are pretty matched. Deploying an automatic production planning model permits optimizing resources for executing garment contracts, thereby reducing contract execution time and improving profits for garment companies. The method of automated production planning based on applying Real-RCPSP and approximation algorithms is an intelligent solution for production in the recent. This also contributes to increasing the proportion of information technology applications in production automation, an inevitable trend in the coming period.

6 Conclusion

Digital transformation in industrial garment enterprises in the current period is necessary to help businesses improve the efficiency of production and business activities. Two essential elements of digital transformation in garment enterprises are the application of IoT devices to monitor production activities and automatic production coordination planning to reduce the time to execute garment contracts. For automated production planning, businesses need to digitize production processes. The paper presented the essential parts of data to implement digitization, proposed the process of digitizing production line data, and specifically applied it in digitizing the sewing line data of TNG company. In order to implement automatic production coordination scheduling, the paper stated the Real-RCPSP problem and proposed a CS algorithm. Next, it experimented on the TNG dataset; the results show that the planning has effectively reduced contract execution time from 5.97% to 33.99% compared to actual time. Therefore, applying these plans will improve enterprises' profits and business efficiency, thereby enhancing the competitiveness and ability of enterprises to integrate into the international environment.

In the coming time, the author will continue to explore the Real-RCPSP problem associated with practical implementation in some production lines and business enterprises in different fields. It will suggest methods to digitize data about the production process and find ways to deploy automated workflow coordination scheduling systems in manufacturing enterprises.

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