Development of STEP-NC Compliant Machine Tool Data Model

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Abstract. To implement STEP-NC based manufacturing, a STEP-NC compliant machine tool data model (STEP-NCMtDm) is developed by using EXPRESS modelling lanugage. It models sufficient machine tool data to 'transfer' STEP-NC machining task-level data to machine tool dependent method-level data. The objective and two main technological aspects of developing STEP-NCMtDM are discussed. The model architecture is analyzed. Machine tool data in STEP-NCMtDm are categorized into two groups: "static data" and "dynamic data", to support further system development. A Web-enabled STEP-NCMtDm (a corresponding XML schema) is developed to support Web-based application. STEP-NCMtDm has been implemented to model a milling machine tool and represent its data in a STEP Part 21 file and an XML file to support STEP-NC based manufacturing.

Keywords: STEP-NC, Machine Tools, Data Model, XML Schema.

1. Introduction

STEP-NC based manufacturing is a newly developed digital manufacturing approach to realize an I^4 (informative, intelligent, integrated and interoperated) manufacturing scenario. STEP-NC has several significant advantages when implemented in the whole CNC manufacturing processes: 1) providing a complete and structured data model to represent various product and technical data at different stages of product development processes, 2) supporting standardized data exchange and sharing within integrated manufacturing systems [1]; 3) bi-directional transfer of high level manufacturing information between CAM and CNC systems, which is impossible with G/M code; and 4) using object-oriented concept "workingstep" to encapsulate machining feature information together with machining operation parameters, which makes manufacturing data reusable.

The most important feature of STEP-NC concept is that of 'machine tool independence'. STEP-NC data model mainly portrays data at the Task-level or the "What-to-do" data. Although it is possible to define data at the Method-level or the "How-to-do" data, such as machine tool trajectory, the main aim of STEP-NC is to allow these decisions to be made by a STEP-NC enabled controller. STEP-NC programs may be written once and used on different machine tools provided that the machine tool has the required process capabilities [2]. Therefore, the implementation of STEP-NC is effectively a process of adapting its data model for different CNC systems. That is, the central issue to implement STEP-NC is therefore the 'transition' from the Task-level data to the Method-level data, or from the "What-to-do" data to the "How-to-do" data.

To do this, it is necessary to have in place a complete and readily accessible database of manufacturing resources, describing data such as product data, cutting tool data. Although some machining process data such as machining parameters, machining strategy, etc. have been defined in STEP-NC Part 10, 11 and 12 [5, 6, 7], these data objects are not adequate for modelling machine tool data in support of STEP-NC enabled machining, especially in a dynamical shop floor environment. Thus, to implement STEP-NC based manufacturing, and to accomplish process planning and scheduling tasks, it is essential to build up a STEP-NC compliant machine tool data model that is able to capture all the required machine tool data for supporting STEP-NC enabled machining. In this paper, a STEP-NC compliant Machine tool Data model (STEP-NCMtDm) is described. When combined with the cutting tool data models defined in STEP-NC, STEP-NCMtDm can form a comprehensive Manufacturing Resource Data Model (MRDM) and ultimately provide sufficient information for STEP-NC based manufacturing.

2. Literature Review

There are some efforts in the area of modelling machine tool data. The project 'Modelling of Manufacturing Resources Information' was carried out at the National Institute of Standard and Technology (NIST) in the USA [8]. It specifies two aspects of manufacturing resources: 1) machine tool (milling machines and vertical/horizontal turning machines); and 2) tool assembly (cutting tools, inserts, tool holders, etc.) This model has been considered as a basis to develop the proposed ASME B5.59-2 standard for representing machine tools. The NIST Manufacturing Resources Model and ASME B5.59-2 are developed to principally satisfy the requirements of manufacturing resource venders but not ideal to support process planning. To overcome this, Kulvatunyou et al developed a UML-based manufacturing resource model based on the NIST model [9]. The new model interacts with the Resource Specific Process Planning (RSPP) module to perform process planning tasks for collaborative manufacturing, but it still lacks the capability of integrating CNC machining to form a close loop manufacturing chain.

Ming et al. introduced a PDES/STEP based production resource model, including data for machine, cutting tool, fixture, gauge tool and fixture [10]. The proposed model considered the external resources in support of the collaborative manufacturing environment. With the other two PDES/STEP-based models (part information model and process planning model), the entire information model can support CAPP applications. Lopec-Ortegsa and Ramirez proposed a STEP-based EXPRESS model to present flexible manufacturing resources (i.e. machining processing resources, handling resources, transportation resources and storage resources) in the shop-floor [11]. This data model was implemented in a STEP-based manufacturing information system.

Several standards have been developed for machine tool data modelling. ASME B5 committee has been working on two draft standards to represent machine tool performance data (ASME B5.59-1) and properties' specification (ASME B5.59-2) respectively. These standards mainly aim to support machine tool vendors. Within ISO, STEP Part 240 [12] stipulates a data model for process planning and eight application objects of Units of Functionality (UoF) '*manufacturing_machine_tool_ resources*' that are of direct relevance to machine tools [13]. In addition, ISO TC39/SC2 is developing standards for enhancing interchangeability between machine tool components and testing machine tools (i.e. test method, test code, test component, etc.).

None of the above models is fit for supporting STEP-NC based manufacturing. Some models (e.g. those developed by NIST, ASME and ISO) are for machine tool vendors and users but not for manufacturing applications such as process planning, shop floor scheduling, etc. Others (e.g. Ming's and Lopec-Ortegas's models, and STEP Part 240) are not completely compatible with the STEP-NC standards. The proposed STEP-NC machine model is to support STEP-NC based manufacturing.

3. Objective

The purpose of developing STEP-NCMtDm is of two-folds. First, it is to meet the data requirements for implementing STEP-NC data model in process planning and scheduling. More specifically, it helps the user determine the "How-to-do" information for CNC machining based on the "What-to-do" information contained in a STEP-NC program. STEP-NC can be considered as a process plan model. It is not supportive of other activities, such as cost estimation, machine tool selection, etc. Thus, the second goal of STEP-NCMtDm is to support these functionalities of process planning in a distributed manufacturing environment.

4. Technological aspects of STEP-NCMtDm

4.1 Machine tool static data and dynamic data

Machine tool data are classified into two types: static and dynamic. If the data stay unchanged during the lifecycle of a machine tool, they are classified as 'static machine tool data', e.g. machine loading capacity and machine tool dimensions. These data are mainly machine tool's specifications, a gross indication of the machining capability of a machine tool. On the other hand, if the data change during different stages of machine tool usage, or take on different values for different applications, they are classified as 'dynamic machine tool data'. Dynamic machine tool data are the key information for realizing flexible process planning and manufacturing. There may be two causes to the changes of a machine tool's dynamic data. The first is to do with the machine tool wear, which leads to an accuracy drift or changes of mechanical and electrical properties. The second is to do with the changes or re-configuration of a machine tool setup.

The static machine tool data, once modelled, can stay unchanged. For the two types of dynamic machine tool data, different data processing and updating procedures can be followed. The first type of dynamic data need to be updated on a more regular basis due to the factors such as machine tool wear. The second type of dynamic data is updated on an irregular basis.

4.2 Modelling language and Web-based data model

The EXPRESS modelling language [14] is used to model STEP-NCMtDm. It defines an 'entity-attributes' type data representation method and can fully support modelling constraints and functions. STEP standard has defined several implementation methods (through Java, C++, etc.). STEP-NC data models are also developed by using EXPRESS. Thus, use of EXPRESS can ensure the compliance of STEP-NCMtDm with STEP-NC, and STEP-NCMtDm can 'service' the STEP-NC data models to form a comprehensive process planning data model in support of STEP-NC based manufacturing.

STEP Part 21 [15] files are neutral files and can be utilized to transfer data between different CAD/CAPP/CAM systems. However, it is not suited for Web-based data publications and transformations. To overcome this problem, a Web-enable data representation method is required. In STEP Part 28 (second edition) [16], a mapping mechanism between EXPRESS and XML schema is defined. Using this mechanism, the STEP-NCMtDm in EXPRESS format can be converted to an XML schema. The STEP Part 21 file with machine tool data can also be presented in the XML file format for Web-based data exchange and sharing.

5. STEP-NCMtDm

5.1 Architecture of STEP-NCMtDm

STEP-NCMtDm is constructed to model the following five sets of data (Figure 1.1): 1) Machine tool general data; 2) Machine tool component data; 3) Machining cost data; 4) Machine tool performance data; and 5) Machining capability data.

Machine tool general data set represents the general information about a machine tool. The root entity is the abstract ENTITY *machine_tool*. The general information modelled about a machine tool includes its id, its location, and the links to other machine tool technique data. Three sub-entities are modelled to represent milling, turning, and mill-turn machine tools respectively.

Machine tool component data set represents the information about each individual component of a machine tool. It is further divided into machine tool axis data (ENTITY *axis*), spindle data (ENTITY *spindle*), workpiece handling device data (ENTITY *workpiece_handling_device*), cutting tool handling device data (ENTITY *cutting_tool_handling_device*) and auxiliary device data (ENTITY *aux_device*).

Machine tool capability data set contains the information which can be used to determine machining capability of a machine tool. In process planning, these data are the key factors to determine whether a machine tool is suitable for a particular machining job. The machining capability, represented by ENTITY *machining_capability* includes machine tool's operation type capability, table loading capability, machinable workpiece size, machining accuracy capability, axis positioning accuracy capability, feeding capability and maximum cutting depth data.

Machine tool performance data set is used along with some other data, in selecting a proper machine tool for machining. Currently, only machine tool's accuracy data is modelled, which involves machine tool resolution (ENTITY *resolution*) and axis repeatability (ENTITY *repeatablility_accuracy*).

Machine tool cost data set is modelled by ENTITY *machine_tool_cost_information* for estimating machining cost in process planning. It keeps the data such as the average cost per setup (attribute setup_cost) and machining hourly rate (attribute machining_cost_per_hour). The process planning system can use these data to calculate the corresponding manufacturing cost.

5.2 Static data and dynamic data

As discussed in section 1.3.1, machine tool data can be divided into two categories: static and dynamic. Different data acquisition and updating methods are implemented for different categories. The dynamic machine tool data can be further divided into two groups according to their updating frequency, regular or irregular. Classification of static and dynamic data is essential for later model implementation. Tables 1-3 show the three types of data for ENTITIES *machine_tool, travelling_axis* and *machine_tool_capability* respectively.

In general, data classification is based on the following guidelines:

- The machine tool's general information and the data related to machine tool or its components' capability are considered as static data.
- The machine tool data related to the machine tool's performance, such as accuracy data, belongs to the first type of machine tool dynamic data. Frequency of updating this type of data depends on the usage of the machine tool.
- The machine tool data related to cutting tool and workpiece handling devices are of the second type

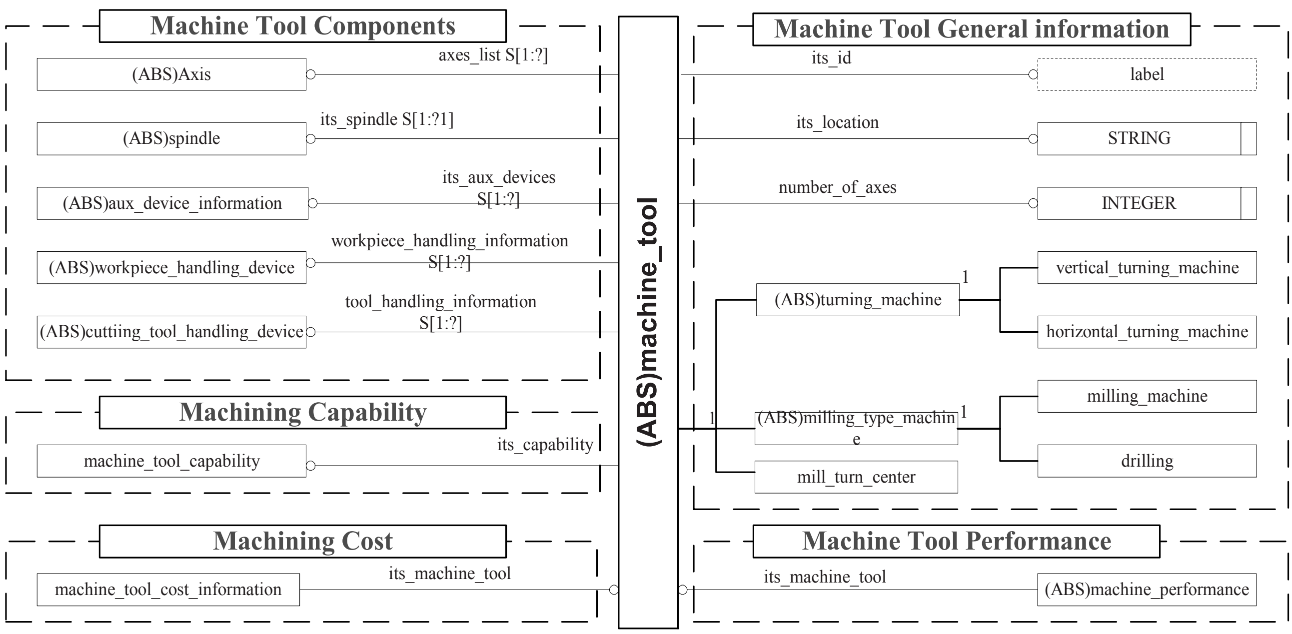

Figure 1.1. Architecture of STEP-NCMtDm

of machine tool dynamic data that needs to be updated on a regular basis. This is due to the fact that different cutting tools handling devices or workpiece handling devices may be utilized for machining a different part. The data are often situational subject to the changes at shop floor.

Table 1.1 Static data and dynamic data in ENTITY *machine_tool*

Static data	Dynamic data	
	Type 1 (regularly updated)	Type 2 (irregularly updated)
its_id	its_capability	tool_handling_information
its_location		
number_of_axis		workpiece_handling_information
axes_list		
its_spindle		its_capability
its_aux_devices		

Table 1.2 Static data and dynamic data in ENTITY *travelling_axis*

Static data	Dynamic data	
	Type 1 (regularly updated)	Type 2 (irregularly updated)
its_name	its_accuracy_information	
its_machine_tool		
its_traveling_range		
its_feeding_range		
rapid_movement_speed		

Table 1.3 Static data and dynamic data in Entity *machine_tool_capability*

Static data	Dynamic data	
	Type 1 (regular updated)	Type 2 (irregular updated)
its_machine_tool	machining_accuracy_information	machinable_workpiece_information
operation_type_information		max_cutting_depth
table_loading_capacity	positioning_accuracy_information	feeding_capability

5.3 Measurement unit

The types of units supported by STEP-NCMtDm are SI units as well as derived or conversion based units defined in ISO 10303 Part 41(ISO 10303-41:1994(E)). If no units are given then, the default values are assumed as defined in Clause 4.2.1 of ISO 14649 Part 10:

- length_measure: millimetre [mm]
- rot_speed_measure: revolutions per second [r/s]
- plane_angle_measure: degrees [°]
- pressure_measure: Pascal [pa]
- speed_measure: meters per second [m/s]
- time_measure: seconds [s]

The default unit for mass_measure (referenced from ISO 10303-41 [17]) is defined as: mass_measure: kilogram [kg]. The power measurement and its measurement unit are defined in ENTITY *power_measure_with_unit* in STEP-NCMtDm. ENTITIES *measure_with_unit* and *si_unit*, and TYPE parameter_value, referenced from STEP Part 41, are utilized to construct ENTITY *power_measure_with_unit*.

6. Web-based STEP-NCMtDm

The EXPRESS-oriented STEP-NCMtDm is not web-enabled. To adapt the distributed manufacturing environment, an XML-oriented STEP-NCMtDm is required to model machine tool data. STEP Part 28 (2nd edition) defines a standardized method to convert EXPRESS data model into a set of XML schema, which can be used to represent machine tool data in a XML document. SETP Part 28 introduces two types of XML schema binding – default XML schema binding (clause 7) and configured XML schema binding (clause 8). This paper utilizes the mapping mechanism corresponding to the default XML schema binding to map STEP-NCMtDm into the corresponding XML schema. These are the standardized mapping mechanisms defined for the EXPRESS elements, such as EXPRESS data type (clause 7.2), defined data type (clause 7.3), entity data type (clause 7.4), entity attributes except DERIVEd attributes and INVERSE attributes (clause 7.6), supertype/subtype relations (clause 7.5), etc.

Figure 1.2 shows a portion of the XML schema (i.e. ENTITY machine_tool) converted from the STEP-NCMtDm EXPRESS data model, and the relationship between *machine_tool* and its subtype ENTITIES *milling_type_machine*, *turning_machine*, and *turn_mill_center*. The header part of the XML schema defines the name space of the STEP-NCMtDm EXPRESS schema and STEP-NC standards. The data part of schema is used to define the main body of the EXPRESS schema of STEP-NCMtDm.

7. Implementation

STEP-NCMtDm has been implemented to model an EMCO Concept Milling 105 milling machine tool [18]. Two types of data file are generated: a STEP Part 21 file (Figure 1.3) and an XML document (Figure 1.4). These files can support adequate machine tool data to meet the data requirements of STEP-NC Part 11 (milling application).

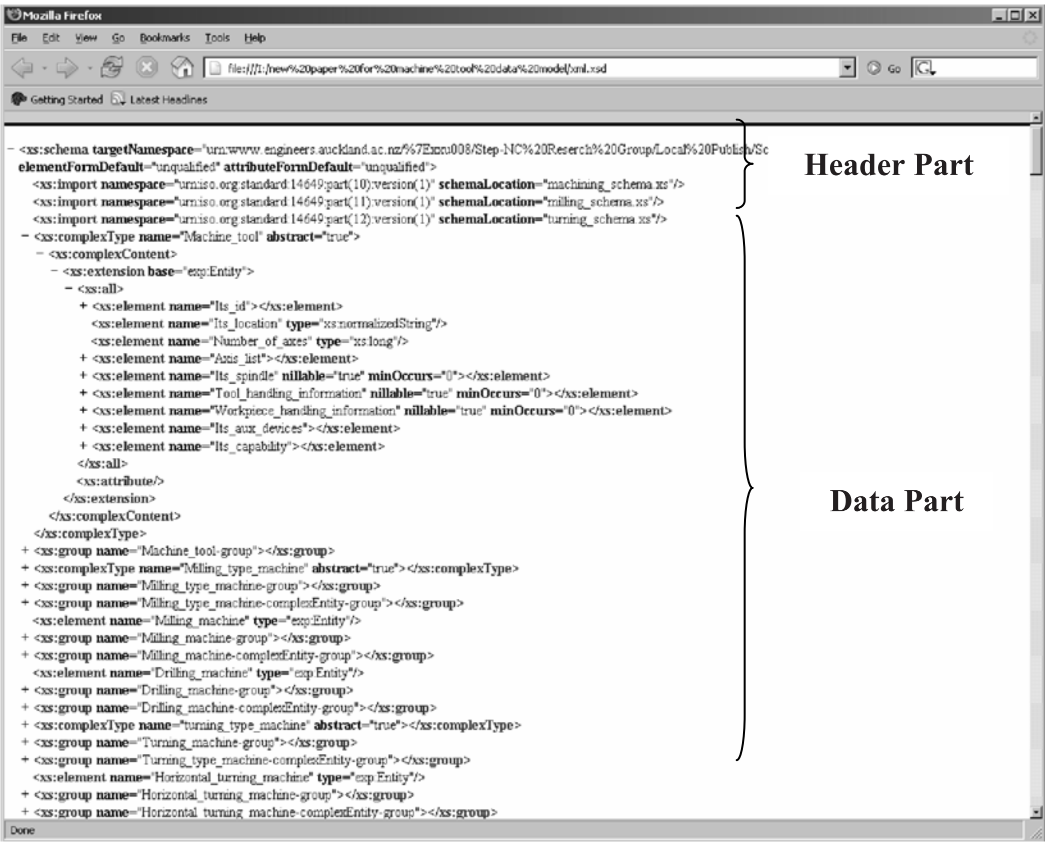

Figure 1.2. XML schema representation of STEP-NCMtDm

```
ISO-10303-21;
HEADER;
FILE_DESCRITION (('machine tool database for Emco concept Mill 105','1');
FILE_NAME ('EMCOMILL105.STP', '2006-12-08', (('ALBERT YANG',$), ('XUN WILLIAM
XU', $), ('DEPARTMENT OF MECHANICAL ENGINEERING, UOA'), $, $, 'IIMS', $);
FILE_SCHEMA (('machine_tool_information', 'machining_schema', 'milling_schema',
'turning_schema'));
END_HEADER;
DATA;
#1= MILLING_MACHINE(LABEL('CONCPET-MILL-105'), 'MANUFACTURING-LAB',
'3', (#2, #3, #4), $, #15, #12, (#11, #14), $, #7);
#2= TRAVELING_AXIS (AXIS_NAME(x), #1, LENGTH_MEASURE(200), #5,
SPEED_MEASURE(5), #6);
#3= TRAVELING_AXIS (AXIS_NAME(y), #1, LENGTH_MEASURE(150), #5,
SPEED_MEASURE(5), #6);
#4= TRAVELING_AXIS (AXIS_NAME(z), #1, LENGTH_MEASURE(250), #5,
SPEED_MEASURE(5), #6);
#5= CUTTING_FEED_RANGE (SPEED_MEASURE(0), SPEED_MEASURE(5));
#6= RESOLUTION (LABEL(STEP-RESOLUTION), #1, $, '1.5','um');
#7= MILLING_TYPE_MACHINING_SPINDLE (LABEL(SPINDLE1), #8, #4, #9, $, #10, $,
#11, .T., LENGTH_MEASURE(55), '4.2',)
#8= ROT_SPEED_RANGE (ROT_SPEED_MEASURE(150), ROT_SPEED_MEASURE
(5000));
#9= POWER_MEASURE_WITH_UNIT (PARAMETER_VALUE(1.1), #19);
#10= LENGTH_MEASURE_RANGE (LENGTH_MEASURE(95), LENGTH_MEASURE
(245))
#11= COOLANT_INFORMATION (.T., (COOLANT_TYPE(mist), COOLANT_TYPE(spay),
COOLANT_TYPE(flood)), PRESSURE_MEASURE(0.5), .T.);
#12= TABLE (LABEL(TABLE1), MASS_MEASURE(10), (#2, #3), $, $, $, #13);
#13= HOLE_FIXTURE (LABEL(HOLE-FIX-1));
#14= CHIP_REMOVE_DEVICE (.F.);
#15= TURRET (LABEL(10-STATIONS-TOOL-CHANGER), '10', (#16, #17, #18), #18,
LENGTH_MEASURE(50), LENGTH_MEASURE(55), WEIGHT_MEASURE(0.7), .T., 9, 7);
```

Figure 1.3. Potion of the Part 21 File for Concept Mill 105

Figure 1.4. Potion of the XML file for Concept Mill 105

For example, for the Entity *milling_technology* in STEP-NC Part 11, which defines the technological parameters of milling operations, the STEP-NCMtDm based Part 21 file/XML file represents data for the following attributes of this entity:

1) Attributes cutting_speed and spindle: Related to an instance of rotation_speed_range defined in Line #8 (Fig. 1.3). The actual spindle rotation

speed must be within this range. The linear cutting speed range can also be set.

2) Attribute feedrate_per_tooth: Related to Line #5, which defines an instance of feeding_range for the cutter. When multiplying the tooth number, a feeding range is calculated to constrain the feedrate value of a cutting tool.

3) Attribute synchronize_spindle_with_feed: Defined as the ninth parameter in Line #7, which defines whether cutting speed and feed of the tool are synchronized.

The corresponding STEP-NCMtDm based XML file supports the same machine tool data for Web-based STEP-NC manufacturing applications.

8. Conclusions

STEP-NC based manufacturing is about utilizing the STEP and STEP-NC data models to support an informative, intelligent, integrated and interoperable CNC manufacturing scenario. The key for STEP-NC based manufacturing is to build machine tool data model to realize the ‘transition’ of STEP-NC tasks level data to machine tool dependent method level data. STEP-NCMtDm models various machine tool data to meet the requirements of STEP-NC compliant process planning and manufacturing activities. It has also been converted into the XML schema, making it Web-enabled.

Machine tool data in STEP-NCMtDm are classified as either ‘Static data’ or ‘Dynamic data’. This classification reflects the nature of different machine tool data, and their different acquisition and updating methods to make efficient and effective machine tool data management. The machine tool data can be exchanged or shared by using either STEP Part 21 files or XML documents.

The proposed data model can be easily extracted to support other types of machine tools and CNC machining applications. Further work includes re-instating the constraint information in STEP-NCMtDm that was lost when using STEP bindings to map its EXPRESS data model into the XML schema. Also under development is a platform on Internet that utilizes STEP-NCMtDm for facilitating on-line bidding process for manufacturing tasks.

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