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The Improved Sub-Structure Chaining Diagram (ISSCD): A Tool for Project Management in the Informal and Semi-Informal Construction Sectors of Developing Countries (DC)

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Abstract Construction projects planned using traditional scheduling tools such as PERT (Program Evaluation and Review Technique), CPM (Critical Path Method) and GANTT (Bar Chart) in the construction sector of developing countries (DCs) are often subject to time overruns. Indeed, this construction industry, which is mainly dominated by the informal and semi-informal sectors, practices project management in a rather special way, given the constraints imposed in this environment. Approaches have been developed in this sector, including the Sub Structure Chaining Diagram (SSCD) [1], which is a sequential approach of a managerial nature. It allows to guide the construction process, to plan or to manage projects by considering as a specific constraint the global "provisional technical budget" of the project, subdivided into sub-projects or sub-works in order to reduce if not to solve the problems of stopping activities which often hinder the process of continuous scheduling of projects. The addition of the "execution time" parameter resulted in the "Improved Sub Structure Chaining Diagram" (ISSCD), with "Budget" and "Execution time of each operation" as key variables. Based on the monthly income of the project owner to be allocated for the execution of the project, the mobilisation time of the sub-budget can be determined for each sub-work of the project, which, added to the practical execution time of the task or operating time, makes it possible to calculate the integral time of the subwork concerned. The application of the ISSCD to a project for the construction of a single-storey building of type F4 in the city of Brazzaville made it possible to determine, on the basis of the monthly savings and the cost of each subwork, the total execution time for all the project's tasks, estimated at 487 weeks, i.e. 10 years.

Keywords Project, project owner, planning, diagram, scheduling, resources, sub-work, sub-budget, mobilisation time, programming path, informal and semi-formal sector

Introduction

In developing countries (DCs), there is a high demand for housing. The shortfall in housing needs is certainly due to demographic pressure in highly urbanised cities, but also to a slackening or disengagement of the public authorities in property investment programs. The new supply is insufficient to curb a demand that is rising too quickly [2]. Also, this field of real estate is characterised by a remarkable imbalance in relation to the current rate of housing production. We are therefore witnessing "self-building" in the construction of individual houses, and even other infrastructures. In some countries, this sector accounts for almost 90% of housing production [3; 4; 5]. Unfortunately, self-building often does not provide quality assurance of the work carried out and often leads to a dead end in the implementation of projects, due to lack of serious planning. Hence, the usual planning methods

(PERT, CPM, GANTT, etc.) seem unsuitable. Furthermore, given that it is not always easy to have all the means to carry out a construction project, some builders, with few means, prefer to start their projects in such a way as to gradually carry out the other parts of the construction after having totalled the sub-budgets of the tasks to be carried out later: a question of trying to find out how to exploit the work before the complete execution of all operations. It therefore seems obvious to innovate in the management of construction projects in these sectors by integrating a much more pragmatic, adapted approach, with the "budget" as the determining variable. The proposed "Substructure Chaining Diagram (SSCD)" [1] has difficulty in functioning because of the "time" factor which is not taken into account. Taking this parameter into account would allow for a much more realistic, better adapted approach with the "technical budget" and the "integral time" of each task as determining variables.

2. Materials and Methods

2.1. Descriptions and Principles of the ISSCD

We had to notice that the SSCD, which is a sequential approach implemented to alleviate the problems arising in project planning, does not meet the requirements of a classical project. Indeed, a construction project is subject to time constraints (deadline to be respected for the execution of tasks), precedence (certain tasks must be executed before others) and production (occupation time of the material or the men who use it). It was therefore necessary to improve the approach in order to meet the requirements of a project and to make the SSCD more practical. Hence the implementation of the Improved Sub Structure Chaining Diagram (ISSCD). As part of the project management scheduling techniques, the ISSCD is particularly well suited to the establishment of work execution schedules, taking into account the realities of the informal and semi-informal construction sectors. It enables the planning of sub works (tasks), the optimisation of resource use, the monitoring of projects and the control of their costs during all phases of their implementation. It is intended for users with initial experience of project management. The special feature of this programme is that it allows:

- Planning a project so as to exploit the work before completion: the predominant style of construction in the informal and semi-informal sectors.
- To know in advance the total time required to complete each part of the work, based on the builder's monthly income. It is represented in the form of a graph called the ISSCD graph, the establishment of which essentially involves three interrelated parameters defining the constraints relating to the quality of the work, its cost and its completion time: determining factors of a schedule. These parameters are: the sub-work, the sub-budget and the time [7].

2.1.1. The sub-structure

The sub-structure is an operation of a certain importance to be carried out according to the requirements of the project (location, foundation, roof, etc.). It represents a part of the work or task. A sub-work is identifiable by a start (start constraint), a duration (work constraint), a cost (resource) and an end (completion constraint). It can be carried out continuously, but also discontinuously. We will thus speak of elementary and compound sub-works [7].

2.1.1.1. The elementary sub-structure

An element of the breakdown of a job that you want to plan is called a sub-element. This decomposition can be more or less important. Indeed, the level of decomposition is "relative" to the work to be planned (The installation of partitions may be an elementary task in the planning of the construction of an R+10 building. On the other hand, the installation of partitions in flat No. 3-101 on the 3rd floor may be an elementary task in the planning of the installation of partitions in this building) [7].

2.1.1.2. The sub-structure composed

When a succession of very short works is studied in relation to the other works, this succession can be considered a composite sub-work. Similarly, a job that can be broken down into so-called elementary sub-jobs is a composite subjob. (Carrying out the plumbing on floor 1 is an elementary task. However, carrying out the plumbing of the building is a compound task) [7].

2.1.1.3. The priority sub-structure

The tasks that ensure the technical sequencing of operations are called priority subworks or command subworks. They are essential to the progress of the project. In the construction of a civil engineering work, all tasks related to the preparation, the foundation of the construction, the body of the structure and all other tasks that can make it impermeable (closed and covered) are priority subworks. For degenerate or multiple choice tasks, the priority of a sub-work is dictated by technical and budgetary constraints (e.g. tasks that are part of the finishing of a construction) [7].

2.1.1.4. The degenerate substructure

Degenerate subworks are subworks that can run in parallel with other subworks without (relatively) interfering with the latter. They are relatively independent. The ISSCD diagram shows degenerate and non-degenerate substructures. For non-degenerate substructures, the choice of the next substructure to be programmed is unique. The SO substructure i+1 starts when the SO substructure i is finished: this is called an end-to-begin (FD) link

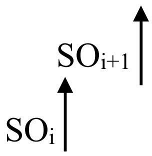

Figure 1: Non-degenerate SO sub-work i

For degenerate substructures, there is more than one choice for programming the next substructure, although the selection of the next substructure is conditioned by both technical and budgetary constraints.

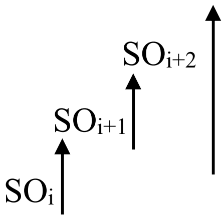

Figure 2: iTwice-degenerate SO subframe (SO i+1, SO i+2)

The degree of degeneration of a structure is given by the number of possible choices to schedule the next sub-structure(s). In addition, it is possible to simultaneously engage as many next sub-structures as the degree of degeneration indicates: this is known as a start-stop connection (DD). The programming of the sub-structures depends on the method of construction evolution. There are two methods of construction development:

- Constructive evolution: it recommends the complete completion of one part of the building before starting another, and so on [1]. The technique of completing, finishing and fitting out the ground floor of a multi-storey building before starting to build the upper floors can be referred to as 'progress'.
- Improving evolution: this recommends carrying out the whole building, task by task [1]. An example is the construction of the shell and then the finish of a multi-storey building [7].

2.1.2. The sub-budget

For any project, resources are usually limited. Thus, the budget is the major constraint in achieving the project's objectives. Although all stakeholders agree on the importance of respecting the project's budgetary limits, it is very often the case that these become difficult to control during the course of the project. It is therefore very important to identify and report on all the data influencing the budget before the implementation phase. In addition, methods and tools must be put in place to ensure that the project's financial commitments are met [6]. This is why it is desirable to associate each sub-project with the corresponding sub-budget for its proper management. For each sub-project, the sub-budget represents the key to its success, but also, more often, the reason for its failure. It is therefore the key parameter in the start-up of a sub-project. Thus, in order to maximise the chances of success in the conduct of a subproject (sub-job), an essential condition must first be met: "to have a budget that fully covers the sub-project" [6]. This budget is often available after a period of time that depends on what the builder has to budget for in relation to his income [7].

2.1.2. Time

Time is the second most important constraint in the project implementation process [7]. It is defined in three dimensions in our case:

2.1.2.1. Time to mobilise the sub-budget

The duration TMi represents the time after which the builder would be able to mobilise the resources necessary for the realisation of the sub-structure SOi. It is calculated in months by the formula:

$$\mathbf{T_{Mi}} = \frac{1}{n}\sum_{j=1}^{n}(\mathbf{t_{Mij}}) \quad (1)$$

With $\mathbf{t_{Mij}} = \frac{SB_i}{R + r_{ij}}$ (2)

j → month

n: nombre de mois pour mobiliser le sous budget SB_i

SBi: sub-budget corresponding to the SO sub-structurei

R: monthly income (monthly savings) to be allocated to the project

r_{ij}: variable component of income

$\mathbf{t_{Mij}}$: mobilisation time in month d for SOi

Properties:

1) If the *rij* are uniform and equal to *ri*, then $\mathbf{T_{Mi}} = \frac{SB_i}{R + r_i}$ (3)

For, $T_{Mi} = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{SB_i}{R + r_{ij}}\right) = \frac{1}{n}\left(\frac{SB_i}{R + r_{i1}} + \frac{SB_i}{R + r_{i2}} + \cdots + \frac{SB_i}{R + r_{in}}\right)$

If $r_{i1} = r_{i2} = \ldots = r_{in} = r_i$, then $T_{Mi} = \frac{1}{n}\left(n\frac{SB_i}{R + r_i}\right) = \frac{SB_i}{R + r_i}$ or $\mathbf{T_{Mi}} = \frac{SB_i}{R + r_i}$

2) Note that $R + r_{ij}$ varies according to the circumstances:

1er case: $r_{ij} = 0 \rightarrow \mathbf{t_{Mij}} = \frac{SB_i}{R}$ (4)

This is the expected mobilisation time (time that can be predicted with certainty).

2eme cas: $r_{ij} \neq 0 \rightarrow \mathbf{t_{Mij}} = \frac{SB_i}{R + r_{ij}}$ (5)

a) $r_{ij} < 0$, then $r_{ij} = -a_{ij}$; where a_{ij} is the budgetary hazard. Thus: $\mathbf{t_{Mij}} = \frac{SB_i}{R - a_{ij}}$ (6)

Consequences:

Two situations could be envisaged:

a1) If $R - a_{ij} < 0 \Leftrightarrow R < a_{ij} \underset{t}{\Rightarrow} t_{Mij} < 0$: no mobilisation in month j for the SO i.

Here the budgetary hazard is greater than the monthly income to be saved for construction. Then the project will experience a delay in the start of SO i if nothing is done the following months to increase the income.

a2) If $R - a_{ij} > 0 \Leftrightarrow R > a_{ij} \underset{t}{\Rightarrow} t_{Mij} > 0$: then the mobilisation time could be extended.

b) $r_{ij} > 0$, then $r_{ij} = +s_{ij}$ where s_{ij} is the budget supplement. Thus, $\mathbf{t_{Mij}} = \frac{SB_i}{R + s_{ij}}$ (7)

This is the case when the constructor finds additional resources to inject in month j for the SO_i. This is referred to as a temporal gain.

R is assumed to vary with the builder's monthly income.

For the same project, T_{Mi} values differ according to the financial means of the builder.

If $T_{Mi} \leq 3$ months, this is referred to as a **short mobilisation time (SMP);**

If $T_{Mi} \in$ [4 months ; 8 months], we speak of an **average duration of mobilisation(ADM) ;**

If $T_{Mi} \in$ [9 months; 12 months], it is called a **long mobilisation time (LMP);**

If $T_{Mi} >$ 12 months, this is called a **very long mobilisation time (VLMT);**

2.1.2.2. Operating time of the sub-construction:

The TSOi time is determined according to the amount of work to be done for a given number of workers and the amount of work that a worker must do per hour or per day. It corresponds to the duration of the completion of a sub-work.

2.1.2.3. Integral time for the completion of the sub-project:

This is the time corresponding to the sum of the mobilisation time of the sub-budget and the operating time of the sub-structure

Let $T_i = \mathbf{T_{Mi} + T_{SOi}}$ (8)

$\mathbf{T_i}$**:** integral time, $\mathbf{T_{Mi}}$**:** mobilisation time of the sub-budget, $\mathbf{T_{SOi}}$: operating time.

- If the project starts with a budget that can cover two, three or more sub-projects, these sub-projects will have zero mobilisation times for the sub-budget (TMi = 0). Indeed, as the budget is already available, one could not wait any longer.

Hence, the integral time of the sub-structure (Ti) would be equal to the operating time of the sub-structure (TSOi).

Demonstration:

$T_i = T_{Mi} + T_{SOi}$, if $T_{Mi} = 0 \underset{t}{\Rightarrow} T_{Ii} = T_{SOi}$

- In the graphical representation of the enhanced SSCD, all time values are expressed in weeks.

Consequences:

Time values expressed in days for operating times and in months for sub-budget waiting times are converted to weeks with rounding up. Therefore:

- x days→1week: case x ≤ 7 days.
- x days→2 Weeks: case 8 days ≤ x ≤ 14 days

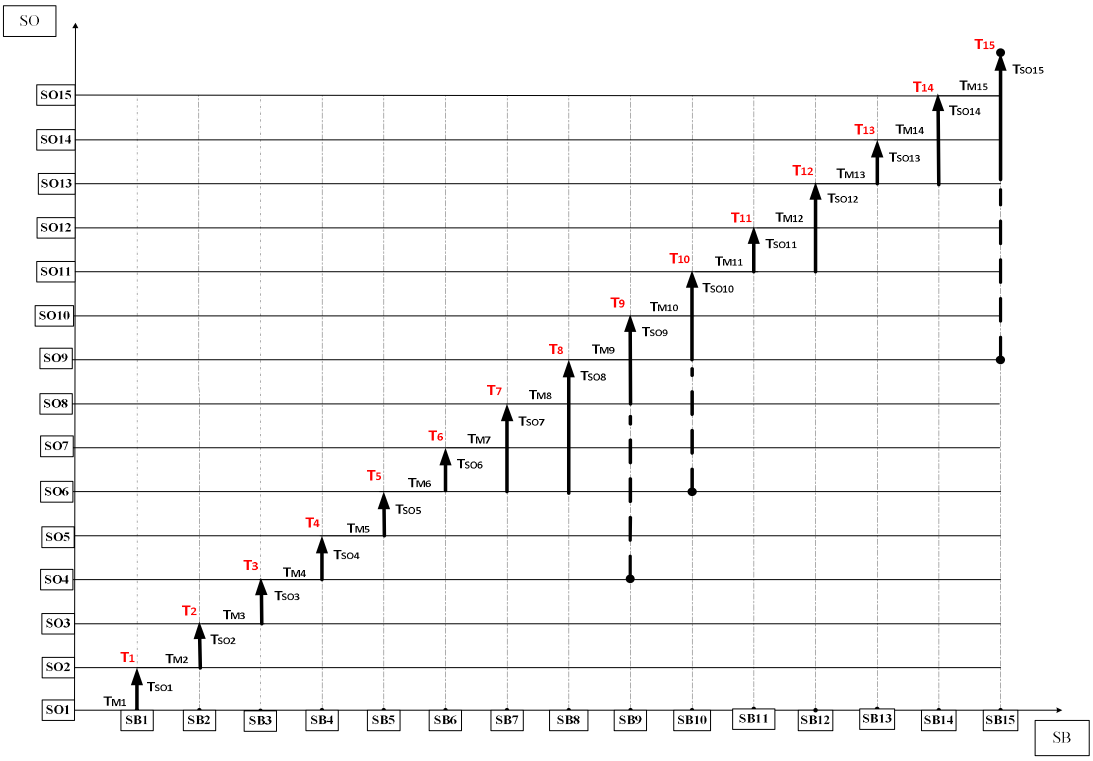

Figure 3: Improved Substructure Sequence Diagram (SSCD) for ground floor construction [7]

Legend: SO1: Site installation and preparatory works; SO2: Layout and earthworks; SO3: Foundation and base; SO4: Masonry and elevation SO5: Roofing (frame and roofing) SO6: Wood and aluminium joinery + glazing SO7: Ironwork; SO8: Plastering; SO9: Electrical fittings; SO10: Plumbing fittings; SO11: Plastering; SO12:

Tiling; SO13: Painting; SO14: Landscaping and roads and bridges; SO i: Sub works i; SB i: Sub-budget for the execution of the sub-project; TMi: mobilisation time of the SBi; TSOi: operating time of the SOi; Ti: integral time of execution of the SOi.

2.2. Project for the construction of a single-storey villa type f4/standing medium

A single-storey building for residential use of type F4 with the following characteristics is considered: a villa of economic type, built in good materials with ordinary modern comfort, meeting the following general characteristics: ordinary facilities (presence of cladding in the shower rooms, kitchen, WC and toilets). The type of construction concerned is classified as "medium standing". The monthly income (monthly savings) to be allocated for the project is $500/month. The building site has already been installed 3 months before; the owner does not mind living without air conditioning. The evaluation of the project in terms of budget and duration per sub-structure gives the following summary table.

Figure 4: 3D view of the single-storey building

Table 1: Summary of the cost estimate for a single storey building for residential use

N°	Designation	Sub-budget ($)	Duration (days)
I	Site installation and preparatory work	1 596,4	4
II	Layout and earthworks	685,03	4
III	Foundation and sub-base	5 333,45	21
IV	Masonry and elevation	13 929, 54	28
V	Roofing (Carpentry and roofing)	4 183,63	10
VI	Wooden carpentry and glazing	3 583,61	7
VII	Plafonnage	3 058,66	5
VIII	Sanitary plumbing	2 675,00	3
IX	Electrical installation	3 209,33	3
X	Interior and exterior plastering	2 282,03	7
XI	Floor and wall coverings	4 175,70	5
XII	Ironwork	825,50	6
XIII	Interior and exterior painting	2 539,33	4
XIV	Sanitation, water/electricity connections	3 778,44	21

Knowing the sub-budgets corresponding to each sub-project, the monthly income (monthly savings) of the Owner, the mobilisation time of the sub-budget of each sub-project is determined by the formula (2). Knowing the mobilisation time of each sub-work and the operating times defined in Table 2, we end up knowing the integral time of each sub-work. We can therefore report in the table, for each sub-project, its sub-budget, its operating time and its mobilisation time.

3. Result

Table 3: Summary of project costs and durations

N°	Code	Désignation	Sous budget ($)	Operating time (week)	Mobilisation time (week)
1	SO1	Installation de chantier et travaux préparatoire	1 596,4	1	14
2	SO2	Implantation et terrassement	685,03	1	14
3	SO3	Fondation et soubassement	5 333,45	3	46
4	SO4	Maçonnerie et élévation	13 929, 54	4	119
5	SO5	Toiture (Charpente et couverture)	4 183,63	2	36
6	SO6	Menuiserie bois et vitrerie	3 583,61	1	31
7	SO7	Plafonnage	3 058,66	1	7
8	SO8	Plomberie sanitaire	2 675,00	1	31
9	SO9	Installation électrique	3 209,33	1	23
10	SO10	Enduits intérieur et extérieure	2 282,03	1	28
11	SO11	Revêtement sol et mur	4 175,70	1	26
12	SO12	Ferronnerie	825,50	1	36
13	SO13	Peinture intérieure et extérieure	2 539,33	1	22
14	SO14	Assainissement, branchements eau/électricité	3 778,44	3	32

The mobilisation time of the sub-budget (respectively the total execution time of the sub-project) is proportional to the sub-budget of the sub-project considered. Indeed, the more expensive the sub-budget, the longer the sub-budget mobilisation time (respectively the full sub-project realisation time). With all the unknowns determined, it is possible, with reference to the construction approach established earlier, to have the sub-works SO6, SO7 and SO8 subjected to budgetary constraints. This is due to the fact that SO5 is immediately previous to the said sub-works (SO5 does not have a single successor) on the one hand and that the technical and budgetary constraints do not match the passage from SO5 to SO9 on the other hand. The path of least resistance imposes the need to carry out SO7 first, then SO8 and then SO6. These constraints, imposed on the subworks, disrupt the standard execution sequence. The schedule changes from the standard path (Ideal Path) to the imposed path (Programming Path). The first operating threshold is reached after the completion of SO7 (236 weeks or 4 years and 7 months of fundraising) following the least cost path.

After all this reasoning, the "ISSCD schedule" for the execution of the work is drawn up below.

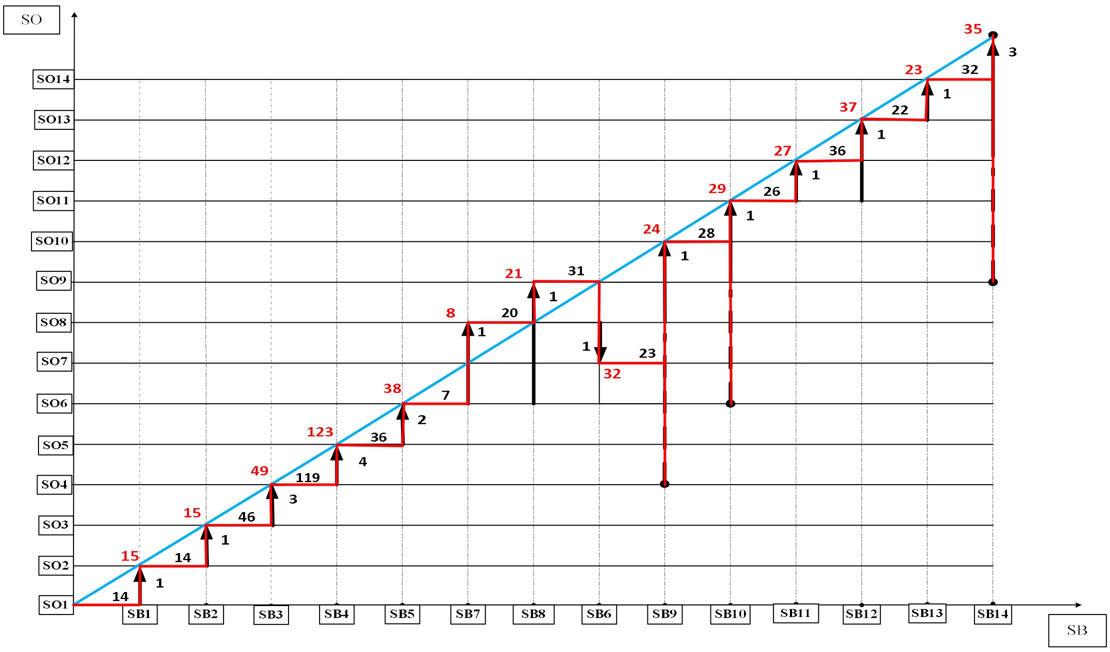

Figure 5: ISSCD construction execution schedule (plotted with Microsoft Office Visio enterprise application)

Legend: SO1: Site installation and preparatory works; **SO2:** Layout and earthworks; **SO3:** Foundation and base; **SO4:** Masonry and elevation; **SO5**: Roofing (frame and roofing); **SO6**: Wood and aluminium joinery + glazing; **SO7:** Ironwork**; SO8**: Plastering; **SO9:** Electrical fittings; **SO10**: Plumbing fittings; **SO11**: Plastering; **SO12**: Tiling; **SO13**: Painting; SO14:Landscaping and roads; **SO i**: Sub works i ; **SB i**: Sub-budget for the execution of the sub-project; **TMi**: mobilisation time of the SBi ; **TSOi**: operating time of the SOi ; **Ti**: total execution time of the SOi.

Ideal path

Programming path

The final operating threshold is reached after 465 weeks of mobilisation and 22 weeks of execution, i.e. a maximum integral time of 487 weeks.

4. Conclusion

The field of construction project management has not been left out of the advances in the construction sector due to scientific research. We can safely assume that the ISSCD (SSCD-improved) enhances the SSCD as part of the project management system practised in the informal and semi-formal sectors of developing countries. It proposes a schedule that takes into account the financial situation of the client, shows how to organise to complete the project completely and from which part of the execution can be changed in order to make the work usable. This is the appropriate scheduling method for project planning in DCs. Indeed, project management does not only consist in solving the technical problems inherent in the project, but also in controlling the whole environment through rigorous management: planning the tasks to be carried out, organising the work, monitoring the execution, costs, communicating information, etc.

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