

The Program Evaluation Review Technique - Improved Sub-Structure Chaining Diagram (PERT-ISSCD): A New Tool for Project Planning in Developing Countries (DCs)

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Abstract The socio-economic environment in developing countries has often posed problems in completing projects on time. Additional costs are often incurred. The results of surveys carried out in construction companies in the Republic of Congo confirm the existence of shortcomings in the management of construction projects in developing countries. We propose a scheduling approach that can be used to plan projects for which effective financing is not assured before work begins, or for which management would be difficult with traditional scheduling methods (PERT and GANTT) because of financial difficulties. This is the PERT-ISSCD (Programme Evaluation and Review Technique - Improved Sub-Structure Chaining Diagram), which is the combination of PERT (programme evaluation and review technique) and ISSCD (Improved Sub-Structure Chaining Diagram). The application of PERT-ISSCD to an R+1 construction project with uncertain financing resulted in a completion time of 128 weeks and 152 days in the context of resource mobilisation based on the client's monthly savings.

Keywords: *planning, duration, mobilisation, resources, project, project owner, scheduling, sub-project, sub-budget, critical path, programming path*

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1. Introduction

In developing countries, there is an imbalance between housing supply and demand [1]. 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 [2,3,4]. Moreover, the socio-economic environment in which developing countries find themselves does not allow projects to be delivered on time. Time overruns are always recorded. Surveys conducted in the Republic of Congo show that almost 90% of construction companies have already missed their deadlines in the execution of their projects [5]. Hence, project scheduling methods such as PERT (Program Evaluation and Review Technique), CPM

(Critical Path Method), Gantt (Bar Chart) or any other planning tool become difficult to adapt. The ISSCD [6] is modestly the best in the informal and semi-informal construction sectors because of its sub-budget mobilisation time, which allows it to plan projects out of time. It allows for the planning of projects that may have several interruptions due to the scarcity of financial resources. But it does not allow for planning while clearly giving the expected duration of projects that are of interest to the formal construction sector. Therefore, it is undoubtedly interesting to add to the PERT the mobilisation time of the sub-budget in order to have the facility to manage projects which, in the formal sector, encounter hazards which undermine the socio-economic environment of developing countries. This means that in planning by the PERT method, it is necessary to take into account not only the operating time (duration of execution of a sub-work or task by the workers), but also the mobilisation time of the sub-budget (important parameter of the ISSCD).

2. Materials and Methods

2.1. PERT-ISSCD Feature

The PERT-ISSCD links the PERT to the SSCD. It is a PERT adapted to the socio-economic realities of developing countries. Indeed, it is applicable in all sectors (formal, informal and semi-informal). As part of project management scheduling techniques, PERT-ISSCD is particularly useful for: planning a project so as to operate the work before its total completion, based on the ideal scheduling path; knowing upstream the total time required to complete each part of the work (sub-work), based effectively on the project owner's monthly income; knowing upstream and explicitly the total time required to complete the work, based on the critical path.

The PERT-ISSCD is represented in the form of a graph called **PERT-ISSCD network** which is a sequence of tasks or sub-tasks using three parameters: the mobilisation time of the sub-budget or resources; the operating time and the integral time.

2.1.1. Mobilisation Time

It is the time that allows the project owner to assemble the necessary budget for the execution of the task at hand. It allows the optimisation of the complete execution of a task in a situation where not all resources are available [6]. This mobilisation time starts when the first deposit from the savings or tontine has been made to build up the budget needed for the execution of a task or subtask and ends when the entire budget has been assembled. It should be noted that before the execution of a task or sub-project, the promoter takes the time to first mobilise the sub-budget that will cover the complete execution of the task. In the PERT-ISSCD schedule, this mobilisation time is shown as a dotted line from step i. After the mobilisation of the sub-budget, it moves on to the execution of the sub-work described by the operating time which ends at step j which is the end of the task execution (Figure 1).

$$T_{Mij} = \sum_{i=1}^n (t_{Mij}) \quad (1)$$

with

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

where :

n: number of tasks concerned by the mobilisation of the sub-budget ; R: monthly income (monthly savings) to be allocated to the project; r_{ij} : variable component of income; t_{Mij} : mobilisation time of the sub-budget for the SO sub-project i; T_{Mij} : total mobilisation time of the project sub-budgets; SB_i : sub-budget corresponding to the sub-project SO_i .

2.1.2. Operating Time

Defined as the actual time of execution of a task or sub-project on site, this time is between the end of the mobilisation time and the end of the execution of the task. It starts only when the self-promoter has been able to mobilise all the funds foreseen for the execution of the

selected task. It is represented by an arrow pointing to the end of the task (Figure 1).

2.1.3. Full Time

This is the time needed to complete a task or sub-task. It is comprised between the start and finish stage of the task. It is the sum of the mobilisation time and the operating time. It is represented in the form of a convex arc or half-ellipse with an indication of the sub-task concerned (Figure 1).

$$T_{ij} = t_{Mij} + t_{ij} \quad (3)$$

We see that for PERT or ISSCD, the sub-project (task) that was represented by an arrow is now represented by two end stages and an intermediate stage. The two end stages characterise the start and end stages of the task, the intermediate stage PX, characterises the order of execution of the task in the project.

The two extreme stages determine the start and end time of the sub-project.

The sub-structure is defined as a part of the structure and its execution requires a detailed analysis of all the constraints within it (Figure 1).

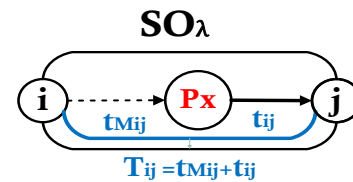


Figure 1. Graphic representation of a sub-work

λ : the serial number of the sub-work.

2.2. Representation of the PERT-ISSCD Network

To carry out this planning, you need to :

1. break down the work under consideration into sub-works ;
2. allocate to each sub-project a budget necessary for its completion;
3. estimate the time required to complete each sub-project;
4. Define the order of priority of the sub-works based on the precedence relations between the different sub-works;
5. draw the PERT and determine the critical path ;
6. determine the time to mobilise the sub-budgets of sub-projects whose financing is uncertain;
7. define the order of habitability of the subworks according to the technical and budgetary constraints in order to determine the programming path;
8. Plot the PERT-ISSCD highlighting the critical path and the programming path.

The critical path is determined as in PERT planning on the basis of the margins or by studying the earliest and latest dates. Indeed, any task whose earliest start or finish time is equal to its latest time is a critical task.

The programming path follows the least-cost path or the ideal path of achieving the project's operating threshold before full completion.

- If full funding for the project is secured, the programming path will be the critical path.
- If the total financing of the project is not assured, the programming path is different from the critical path. It will simply be the path of mobilised resources taking into account technical and budgetary constraints.

In the PERT-ISSCD schedule, the sequence of sub-works within the mobilisation is numbered by the central nodes of the sub-works. This is the order in which the sub-works are executed along the sub-work scheduling path.

We will propose a summary representation of the PERT-ISSCD diagram by illustrating the planning of a single-storey building for residential use without all the details of the duration of the subworks.

We break down the work into 12 sub-works or tasks as follows:

SO1: earthworks and layout; SO2: reinforced concrete and masonry; SO3: roofing; SO4: carpentry; SO5: electricity; SO6: plumbing; SO7: plastering; SO8: wall covering; SO9: floor covering;

SO10: glazing; SO11: painting; SO12: landscaping and roadworks.

In order to simplify the presentation, each sub-work is assigned a letter of the alphabet so as not to overload the graph. We therefore have the simple coding system from A to L which expresses the 12 sub-works mentioned.

We will list the tasks, specifying for each one: the dependency relationship; the operating time; the mobilisation time.

Table 1. List of sub-works for a single-storey residential construction project

Sub-work	Code	Designation of the task	Background	t_{MSO}	t_{SO}
SO1	A	Earthworks and layout	without	t_{MA}	t_A
SO2	B	Reinforced concrete and masonry	A	t_{MB}	t_B
SO3	C	Roofing (frame and roofing)	B	t_{MC}	t_C
SO4	D	Carpentry	C	t_{MD}	t_D
SO5	E	Electricity	C	t_{ME}	t_E
SO6	F	Sanitary plumbing	C	t_{MF}	t_F
SO7	G	Plafonnage	E	t_{MG}	t_G
SO8	H	Plaster	D, F, G	t_{MH}	t_H
SO9	I	Cladding and tiling	H	t_{MI}	t_I
SO10	J	Glazing	I	t_{MJ}	t_J
SO11	K	Paint	J, L	t_{MK}	t_K
SO12	L	Development and roads	F	t_{ML}	t_L

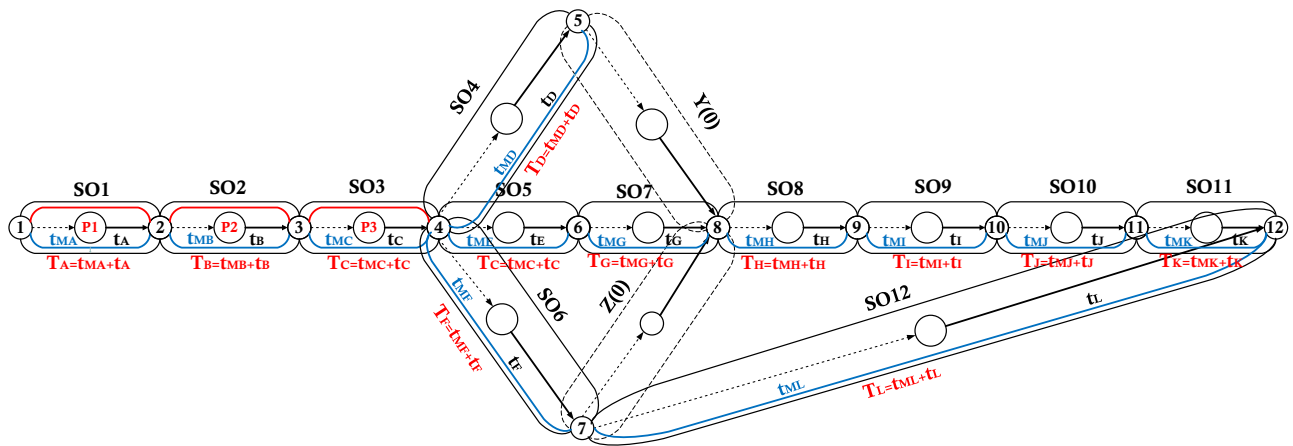


Figure 2. PERT-ISSCD network representation of a single-storey residential building project

SO1: Earthworks and layout; SO2: Reinforced concrete and masonry; SO3: Roofing (framework and roofing); SO4: Carpentry; SO5: Electricity; SO6: Plumbing; SO7: Plastering; SO8: Plastering; SO9: Cladding and tiling; SO10: Glazing; SO11: Painting; SO12: Landscaping and external works.

The red lines represent the critical path and the blue represents the programming path of the sub-works.

The first three tasks SO1, SO2 and SO3 follow a successive execution;

Tasks SO4, SO5 and SO6 are divergent. They follow a simultaneous execution;

Tasks SO4, SO6 and SO7 are convergent. Hence the creation of dummy tasks Y and Z to enable the start constraint of task SO8.

Tasks SO8, SO9, SO10 and SO11 are successive tasks.

Tasks SO11 and SO12 complete the project.

The duration of the project is a function of the durations of the tasks and the different precedence relationships that link the different tasks.

2.3. Expression of Total Project Duration

2.3.1. Project Funding Provided

Consider the $A_{\lambda c}$, $\lambda \in [1, n]$, tasks (activities) that make up the critical path; the total project duration is:

$$T = T_{1c} + T_{2c} + \dots + T_{nc} \quad (4)$$

where $T_{\lambda c} = t_{\lambda c} + t_{M\lambda c}$, duration of activity A_{λ} ,
where $t_{M\lambda c} = 0$

$t_{\lambda c}$: the operating time of task A_i of the critical path;

$t_{M\lambda c}$: the mobilisation time of task A_i of the critical path.

Thus $T_{\lambda c} = t_{\lambda c} + t_{M\lambda c} = t_{\lambda c} + 0 = t_{\lambda c}$, i.e. $T_{\lambda c} = t_{\lambda c}$,

Or

$$T = t_{1c} + t_{2c} + \dots + t_{nc} \quad (5)$$

$$T = \sum_{i=1}^n t_{\lambda c} \quad (6)$$

The total duration is reduced to the sum of the operating times of the tasks A_{λ} which make up the critical path: typical formula for calculating the total duration of the project using the PERT method. PERT-ISSCD becomes PERT again.

2.3.2. Full Project Funding not Secured

We have $t_{Mi} \neq 0$, $i \in [1, n]$.

The total project duration is the sum of the durations of all the tasks.

$$T = \sum_{i,j=1}^n T_{ij} = \sum_{i,j=1}^n (t_{ij} + t_{Mij}) \quad (7)$$

Assuming that the sub-work SO_{ij} between step i and step j is numbered λ^{eme} sub-work, i.e. SO_{λ} . We can therefore write $SO_{ij} = SO_{\lambda}$.

The relationship (7) can still be written as:

$$T = \sum_{\lambda=1}^n T_{\lambda} = \sum_{\lambda=1}^n (t_{\lambda} + t_{M\lambda}) \quad (8)$$

The total project duration is calculated by adding the operating time and the mobilisation time of the sub-budget for each task: the basic formula for calculating the total planned project duration using the PERT-ISSCD method.

It is important to be aware that in some cases, even if funding is not certain, some tasks (e.g. the first task of the project) have a zero mobilisation time. This is because once the project has started, it is assumed that the mobilisation times of the sub-budgets of the funded tasks are zero.

- The duration of task A_i is:

$$T_{\lambda} = t_{\lambda} + t_{M\lambda} \quad (9)$$

with $t_{\lambda} > 0$ et $t_{M\lambda} \geq 0$, $\lambda \in [1, n]$.

- The total duration of the project is:

$$T = T_1 + T_2 + \dots + T_{\lambda} + \dots + T_n = \sum_{\lambda=1}^n T_{\lambda} = \sum_{\lambda=1}^n (t_{\lambda} + t_{M\lambda}) \quad (10)$$

Discussion:

1. If the budgets allocated to the execution of the first p tasks only are available, we will have:

$$T = t_1 + t_2 + \dots + T_{\lambda} + \sum_{\lambda}^n (t_{\lambda} + t_{M\lambda}) \quad (11)$$

$$= \sum_{\lambda=1}^p t_i + \sum_{\lambda=p}^n (t_{\lambda} + t_{M\lambda})$$

With $t_{\lambda} > 0 \forall \lambda \in [1, n]$;

$t_{M1} = t_{M2} = \dots = t_{Mp} = 0$, $t_{M\lambda} \neq 0$, $\lambda \in [p, n]$.

This explains the possibility of having one or more tasks with zero mobilisation time. Thus for these tasks, the duration is reduced to the operating time,

$$T = \sum_{\lambda=1}^p t_{\lambda} + \sum_{\lambda=p+1}^n (t_{\lambda} + t_{M\lambda}) \quad (12)$$

with $t_{\lambda} > 0 \forall \lambda \in [1, n]$;

$t_{M\lambda} = 0$ si $\lambda \in [1, p]$ et $t_{M\lambda} \neq 0$ si $\lambda \in [p, n]$.

2. It may happen that the project is stopped at a certain phase of the project's progress for some financial, functional or organisational reason and everything may return to normal until the project is completed. As this is a single stop, the total duration of the project is:

$$T = \sum_{\lambda=1}^p t_{\lambda} + [t_{(p+1)} + t_{M(p+1)}] + \sum_{\lambda=p+2}^n t_{\lambda} \quad (13)$$

with $t_{M\lambda} = 0$ si $\lambda \neq p + 1$.

Application to construction projects: case of an R+1 building for residential use.



Figure 3. 3D view of the R+1 building

Presentation of the project

A property developer has commissioned a study of a one-storey building (architectural and structural plans) for residential use. It is a modern villa, built in good materials with ordinary modern comforts, with the following general characteristics: ordinary fittings (presence of cladding in sanitary and kitchen areas). He chooses the option of finishing the shell and then starting to raise the funds to complete his project. He would like to know how long it would take him to complete his project if he saved \$2481.1 each month (monthly income to be allocated to complete the project).

Table 2. Summary of the Quantities and Estimates for the R+1 building

N°	Code	Designation	Sub-budget (\$)	Duration (day)
01	SO1	Site installation and preparatory work	6 750,83	8
02	SO2	Foundation and sub-base	8 831,00	17
03	SO3	Masonry and ground floor elevation	6 562,60	14
04	SO4	High floor DRC	6 811,63	12
05	SO5	Masonry and floor elevation	7 422,73	14
06	SO6	Stairs	887,64	3
07	SO7	Carpentry and roofing	7 030,37	16
08	SO8	Plaster	2 153,26	9
09	SO9	Sanitary plumbing	8 015,85	5
10	SO10	Electricity	13 741,42	5
11	SO11	Aluminium and glass joinery	11 336,32	6
12	SO12	Plafonnage	1 224,75	4
13	SO13	Tiles	5 984,83	6
14	SO14	Paint	11 704,02	7
15	SO15	Sewerage and roads	3 992,26	12
16	SO16	Interior and exterior design	15 697,10	14
Total			118 146,63	

3. Results

3.1. The Total Duration of Unfunded Sub Works

The total duration of the unfunded sub-works time depends on the mobilisation times of the unfunded tasks. The calculation of mobilisation times is presented in Table 3 below:

Table 3. Summary of mobilisation times for the R+1 building

Sub-works	Sub-budgets (\$)	Time to mobilise funds (week)
SO8	2 153.26	4
SO9	8 015.85	14
SO10	13 741.41	24
SO11	11 336.32	20
SO12	1 224.75	2
SO13	5 984.83	10
SO14	11 704.02	20
SO15	3 992.26	7
SO16	15 697.10	27
Total mobilisation time		128

The total duration of the unfunded sub works is:

$$\sum_{\lambda=8}^{16} T_{ij} = \sum_{\lambda=8}^{16} t_{ij} + \sum_{\lambda=8}^{16} t_{Mij} = 128 \text{ weeks} + 68 \text{ days} \quad (14)$$

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).

3.2. Total Project Duration

It is the sum of the total duration of the funded sub-tasks and the total duration of the unfunded sub-tasks. The case of line (12) which takes into account the possibility of having one or more tasks with a mobilisation time of zero. As a reminder:

$$T = \sum_{\lambda=1}^p t_{\lambda} + \sum_{\lambda=p+1}^n (t_{\lambda} + t_{M\lambda}) \quad (15)$$

In our case, we have:

$$T = \sum_{\lambda=1}^7 t_{\lambda} + \sum_{\lambda=8}^{16} (t_{\lambda} + t_{M\lambda}) \quad (16)$$

$$= 128 \text{ weeks} + 152 \text{ days} = 2 \text{ years et 8 months}$$

3.2. Programming of Sub-works

In a project, the technical constraints include the following:

- Some tasks must be completed before others. Thus, there are start tasks and end tasks;
- Tasks are executed according to precedence relations. Successive tasks are executed one after the other and simultaneous tasks (convergent and divergent) are executed in parallel.

Budgetary constraints require that tasks for which funding is available be carried out.

Applying the technical and budgetary constraints on our project, the order of execution of the tasks in the work flow imposes the sequencing presented in the table below (Table 4):

Table 4. The order in which the sub-works are switched on

N°	Order	Sub-works	Designation of the sub-works	Sub-budgets (\$)	Operating time (days)	Time to mobilise funds (weeks)
01	P1	SO1	Site installation and preparatory work		8	0
02	P2	SO2	Foundation and sub-base		17	0
03	P3	SO3	Masonry and ground floor elevation		14	0
04	P4	SO4	High floor DRC		12	0

N°	Order	Sub-works	Designation of the sub-works	Sub-budgets (\$)	Operating time (days)	Time to mobilise funds (weeks)
05	P5	SO6	Stairs		3	0
06	P6	SO5	Masonry and floor elevation		14	0
07	P7	SO7	Carpentry and roofing		16	0
08	P8	SO8	Plaster	1 301 799	9	4
09	P9	SO11	Carpentry	6 853 600	6	20
10	P10	SO9	Sanitary plumbing equipment	4 846 140	5	14
11	P11	SO10	Electricity	8 307 650	5	24
12	P12	SO15	Sewerage and roads	2 413 600	12	7
13	P13	SO12	Plafonnage	740 450	4	2
14	P14	SO13	Tiles	3 618 250	6	10
15	P15	SO14	Paint	7 075 900	7	20
16	P16	SO16	Interior and exterior design	9 490 000	14	27

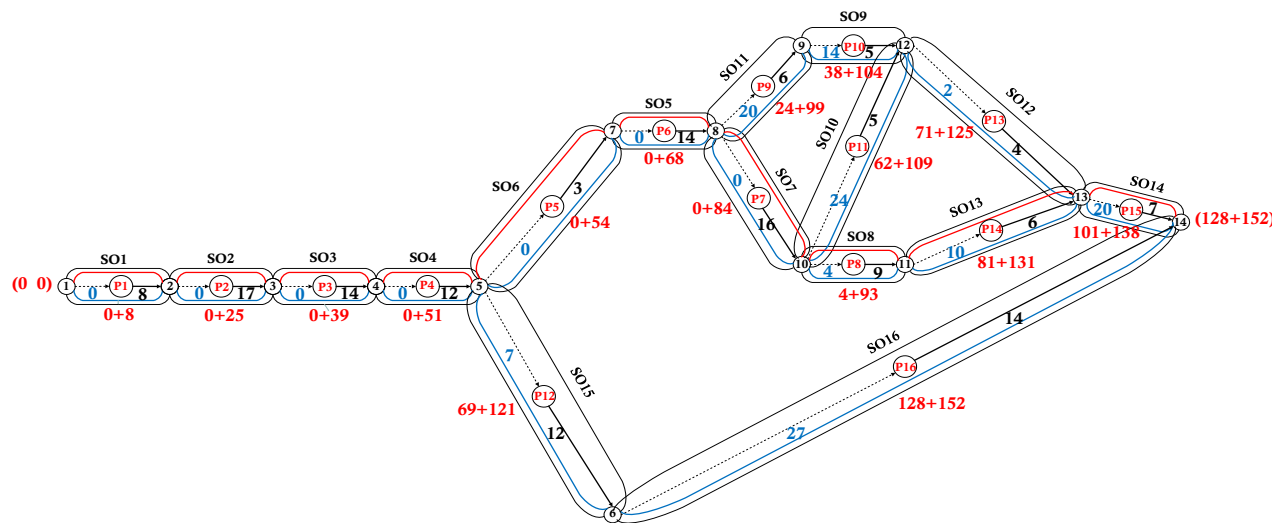


Figure 4. PERT-ISSCD planning of the R+1 building

SO1: Site installation and preparatory works; SO2: Foundation and basement; SO3 : Masonry and elevation ground floor; SO4: High floor ground floor; SO5: Masonry and elevation first floor; SO6: Stairs; SO7: Carpentry and roofing; SO8: Plastering; SO9: Sanitary plumbing; SO10: Electricity; SO11: Alu-glass joinery; SO12: Ceiling; SO13: Tiling; SO14: Painting; SO15: Sewerage and external works; SO16: Internal and external fittings. The red lines represent the critical path and in blue the programming path of the sub works.

The exact duration of the work is 128 weeks and 152 days, or 32 months.

All funded tasks have a zero mobilisation time (blue on the digram).

The first seven tasks follow a continuous execution in succession. As long as the current task has not been completed, no other task can be started. These are tasks SO1 (Site installation and preparatory works), SO2 (Foundation and basement), SO3 (Masonry and ground floor elevation) and SO4 (Ground floor elevation), SO6 (Stairs), SO5 (Masonry and floor elevation) and SO7 (Carpentry and roofing). There are no budgetary constraints for these tasks, they are only subject to technical constraints. Because they are financed.

For unfunded sub-projects, the programming of a task is conditional on the recovery of funds after a period of time called the sub-budget mobilisation time.

In the context of mobilisation, divergent tasks are executed simultaneously only when the budgets allocated to them are all available. Otherwise, the execution of the sub-tasks follows the programming path materialized by the letters PX, X being the order of execution of the sub-tasks. The execution of the project starts with the start task SO1 (Site installation and preparatory work) of order P1 and ends with the tasks SO14 (Painting) and SO16 (Interior and exterior fittings) of order P15 and P16 respectively. The interlocking of all the sub-tasks of the project is defined in Table 3.

The programming path follows the order given by the Px, which takes into account technical and budgetary constraints.

4. Conclusion

PERT-ISSCD is a scheduling approach to be an effective project planning and control tool in construction project management in developing countries. We can immediately discover the origin of the delay if it could occur by the critical path analysis. Indeed, by this method, we can explicitly know the full completion time of a construction project from its start-up phase, and the execution time of each sub-project by the analysis of the mobilisation terms adopted. It can be a solution approach to time overrun in the construction sector of developing countries.

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