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Scheduling of Post-Flood Recovery Project with Flexible Project Structure

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Abstract: Flood events around the world result in the loss of human lives, disruption, damage to economic, infrastructural and ecological systems. Although, different frameworks to manage flood events exist; however, the complexity (i.e. adjustment and adaptation) associated with some of these approaches is often limited by constraints of time and resources. Therefore, this study attempts to apply a flexible project structure to schedule a post-flood recovery project (PFRP). Twenty-five (25) restorative activities in a PFRP were identified, categorised and scheduled as resource-constrained project scheduling problem with a flexible structure (RCPSP-FS). Monte Carlo simulation was used to reflect the uncertain characteristics of each restorative activity. PFRP completion time was 42 and 86 days under time and resource constraints assumptions, respectively. Thirty- four (34) network paths (sub-projects) were identified and grouped into 4 restorative measures as follows: (i) removal of hazardous materials (ii) evacuation of injured persons (iii) provision of flood technology warning system and technical facilities and (iv) construction of shelter, homes and bridges. Time and cost flexibility values for the network paths range from 6 to 63 days, and 14.79 to 288.77 thousand USD, respectively. Time and schedule sensitivity analysis revealed the impact of each restorative activity on simulated project completion time. Based on these results, it is concluded that a flexible project structure can respond to changing circumstances during post-flood restoration efforts which allow more degree of freedom in activity scheduling, flood events measures and cost alternatives.

Keywords: Flood, flexible project structure, disruption, project activities.

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1. Introduction

Flooding is often classified as a natural event; however, it has become a global occurrence with the aftermath of destruction. Smith (2013) reported that over 3000 flood events occurred from 1990 to 2010, and 3 billion people were estimated to have been rendered homeless. Similar flood events were cited by Gautum and Van der Hoek, 2003; Ulbrich et al., 2003; Engel, 2004; Thieken et al., 2006; Annegret et al., 2013; Samuel et al., 2015 and Thieken et al., 2013.

Flood events can be managed using structural and non-structural measures (Thampapillai and Musgrave, 1985). Structural measures (SM) involve carrying out physical activities (i.e. engineered solutions) such as (i) construction of dams, reservoirs, drainages, bridges, and resilient structures (ii) provision of technical facilities, flood shelters and embankments, etc. (Saidu and Dharmasiri, 2015). Shrestha et al. (2019) defined non-structural measures (NSM) as pre-disaster management strategies (i.e. proactive preparedness). In NSM, some of the approaches available to mitigate against disruptions include (i) installation of flood technology warning systems, emergency response, and evacuation planning (ii) use of insurance policy and (iii) land use planning (Correla et. al., 1998).

Disruptions are events characterized by breakdown, disturbance, and failure. These events can negatively affect efforts to achieve a system's objective (Kikwasi, 2012). To remain competitive despite system disruption, efforts must be aggregated to return to a pre-disruption status. For example, in the event of a natural disaster, restoration efforts could be any of the following: emergence response, evacuation planning, resettlement plan, construction of infrastructure, etc. Logically, both renewable (human, machines, tools and equipment) and consumable resources (energy, money, etc.) will be utilised. Also, such efforts though temporary involve a set of activities to be scheduled within the specified start and finish time. This temporary endeavour could be termed a "recovery or restoration project".

Projects can be used to actualize organisational and sustainable goals (Miltiadis and Lazar, 2010); also, they can be regarded as a change agent of modern society (Odedairo, 2016). In project management, project scheduling (PS) is a decision problem (Odedairo and Oladokun, 2018). In the project scheduling problem (PSP), factors such as choices/decisions on activity implementation, flexibility in activity schedule, uncertainty, and resource allocation must be considered. On flexibility (often used interchangeably as 'agility' and 'responsiveness'), Bernardes and Hanna (2009) provided thirteen (13) definitions; these definitions emphasized the need for an organisation to build capabilities (i.e. ability) required to adjust and adapt to business uncertainties. These circumstances could be limitations, complexities, and variations arising from increased competition and technological improvements (Odedairo and Nwabuokie, 2018). The quality of decision making (i.e. responsiveness) during this period is dependent on the flexible structure available at different decision levels.

Although projects are characterized by uncertainties, project flexibility is a planning approach available to simultaneously structure and schedule project activities. For example, post-flood measure(s) is one of the phases in the flood risk management process which consists of a broad spectrum of activities to ensure a return to normal life (Simonovic and Carson, 2003; Deltares, 2010). These measures, mostly executed as post-flood recovery project (PFRP) include but limited to the following: recovery of the physical environment, rehabilitation and reconstruction of community infrastructures, building long-time flood resilience framework, provision of assistance to flood victims, cleaning efforts, environmental impact assessment of flood, etc. (ADB, 2006; UNHabitat, 2010; Jouannic, 2016; Nepal Flood, 2017).

Generally, these projects are constrained with physical, technological, time and resource limitations. Consider, for example, activity processing time and resource requirements in projects are subject to errors because they are not precisely known (Artigues et al., 2013). Also, the complexities associated with project structure (i.e. activity implementation and precedence relations) can limits opportunities for alternative scheduling and cost adjustments in PFRP. Hence, the need for an approach within the project planning framework that can leverage choices/decisions while responding to changing situations. This immediately leads to the question of how to apply a flexible project structure to schedule a PFRP.

The rest of the paper is organised as follows. In section 2, execution modes and project structures within the context of PSP were explained. In section 3, the study methodology was highlighted. In section 4, results were discussed and the study concluded in section 5.

2. Project Scheduling Problem: Execution Modes and Project Structures

Demeulemeester and Herroelen (2002) categorized PSP as an integrated problem involving machines and additional resources. Möhring (1984) conceptualized scarce resources and time in PSP as resource-constrained project scheduling problem (RCPSP) and time-constrained project scheduling problem (TCPSP), respectively. In the standard RCPSP, unless differently stated, each activity can only be executed in a single execution mode comprising of known processing time and non-consumable resources (Hartmann and Briskorn, 2010).

Execution modes are alternative ways to process an activity characterized by time and resource information (i.e. different durations and costs). For example, consider a project activity (*i*) where a company is required to supply 10,000 litres of drinking water. There are several ways this could be done. Activity (*i)* can be executed by company A using truck of capacity X (mode 1) or by company B using a truck of capacity Y (mode 2). While both options for restocking are legitimate; however, the chosen mode will depend on the type of truck (i.e. capacity) and its processing time.

Multi-mode RCPSP (MM-RCPSP) is a variant of the standard RCPSP characterized by multiple execution modes within specified precedence-resource constraints. MM-RCPSP will revert to the standard RCPSP if activity processing is restricted to a single mode. Also, precedence constraints associated with each mode in MM-RCPSP has a rigid structure (RS). An RS demands that all activities, precedence constraints, and resources in a project are known in advance and must be scheduled (i.e. implemented).

In real life, most projects tend to be designed within the framework of an RS. Kellenbrink and Helber (2015) and Vanhouwaert (2018) concluded that the structure of a project can impact the project objective (makespan, cost and quality). A flexible project structure can adjust (i.e. accommodate) and adapt to the effects of uncertainty within the scope of a project (i.e. response to schedule deviations). In this study, a flexible project structure (FPS) and flexible structure (FS) are used interchangeably. Kellenbrink and Helber (2015) opined that a flexible structure presents opportunities for multiple decisions/choices to implement activity based on a defined precedence relationship. In essence, a flexible project structure is sensitive to system disruptions and can utilize different choices.

To take advantage of the benefits offered by flexible project structure, an extension to the standard RCPSP was proposed by Kellenbrink and Helber (2015) namely the RCPSP-FS. In RCPSP-FS, the concepts of compulsory, alternative, optional and dependent activities were introduced. Usually, choices among alternative activities are potential modes of execution with a degree of freedom. In RCPSP-FS, it is possible not to implement an activity; and if it is mandatory, its implementation depends on the processing of its preceding and succeeding activities. Invariably, in RCPSP-FS, constraints can only be enforced if the preceding and succeeding activities connected with the constraints are implemented in the schedule.

Servranckx and Vanhoucke (2018) commented on RCPSP-FS and argued that it is an RCPSP with an alternative project structure. They showed that the problem is a combination of two decision sub-problems which are (i) the decision on activity scheduling and (ii) determination of alternative project structure. In Table 1, a comparison between MM-RCPSP and RCPSP-FS is presented.

Table 1. Comparison between MM-RCPSP and RCPSP-FS

Characteristics	MM-RCPSP	RCPSP-FS
Structure	Rigid	Flexible
Precedence	Precedence constraints must be respected irrespective of the mode	Enforcing precedence constraints is a function of the definition of an activity (i.e. compulsory, alternative, optional and dependent)
Modelling flexibility	Low	High
Execution modes	Limited to modes defined before the commencement of the project	New modes can be defined while a project is being executed.

Table 2. Basic notations and their definitions

Notation	Definition
AN	Activity Number, i
PREC($\|i \rightarrow j\|$)	($i\|i \rightarrow j\|$); Precedence relationship between activity i and j
CP	Critical Path (CP), if activity lies on CP; Yes =1, otherwise, No = 0
DAPD	Deterministic Activity Processing Duration (hours)
SAPD	Simulated Activity Processing duration (days)
PCT	Project Completion Time or Makespan (days)
SPCT	Simulated Project Completion Time (days)
MCSRun	Monte Carlo Simulation Run
CI (i)	Criticality index, CI (i), the probability that activity i still lies on the critical path using SAPD
CRI(i)	CRI is Pearson's product-moment cruciality index, a correlation between SAPD and SPCT
SSI (i)	Schedule Sensitivity Index, the relative importance of individual activity while considering CI(i)
CST(i)	Estimated cost of executing flood recovery activity
EMA	Emergency Management Agency
Pr(i)	Probability of activity i
Tf_i	Total float for activity i
σ	Standard deviation

3. Methodology

The basic notation and terminologies used in this study are presented in Table 2.

3.1 Data collection

The perennial challenge of rainfall-induced flooding in Ibadan city (1951, 1955, 1960, 1961, 1963, 1969, 1973, 1978, 1980, 1982, 1984, 1986, 2011, 2013, 2016) necessitated the need for an urban flood management project by the state government (Agbola et al., 2012; Vanguard News, 2017). From project reports and personal interviews, information on duration, sequence, precedence relationships and cost of executing activities were obtained from a recent PFRP. The regulatory agency gave assess to only one post-flood project.

3.1.1. Modelling characteristics for PFRP

The RCPSP-FS model configuration proposed by Kellenbrink and Helber (2015) was adapted to PFRP. In RCPSP, the makespan obtained using critical path methodology (CPM) is usually taken as a lower bound value. In PFRP, scheduling decisions and FS configurations are expected to increase project completion time. The equivalent modelling configuration in PFRP is presented in Table 3. In Table 4, restorative activities are described and classified.

Table 3. Modelling configuration in PFRP

	Modelling configuration
CA	Compulsory implementation of activity
NCA	Non –compulsory activity
AC	Choices trigged by C and NC

Table 4. Description and classification of activities in PFRP

	Description	Classification						
AN	Flood Restoration Activity	CA	NCA	AC	DAPD (hrs)	PREC	CST(₦)*	Supervisors
A	Flood area survey	Yes	-	Nil	48	-	3,000,000	7
B	Consultation with community leaders/Eye witness	Yes	-	A	24	-	30,000	2
C	Mobilisation of the emergency response team	Yes	-	Nil	24	A	2,000,000	5
D	Mobilisation of the medical support team	Yes	-	Nil	24	A	4,000,000	5
E	Preparation of GIS maps for the relief and recovery	-	Yes	G	48	A	200000	2
F	Installation of flood warning signals	Yes	-	Nil	48	E	5000000	1
G	Real-time flood disaster assessment	Yes	-	E	24	A	100000	2
H	Clearing and cleaning of debris and rubbles.	Yes		Nil	240	A	100000	2
I	Removal of hazardous material from the affected area.	Yes		Nil	48	C, D	900000	1
J	Evacuation of hazardous materials.	Yes	-	Nil	48	I	2500000	1
K	Transportation of debris	Yes	-	Nil	360	H	3500000	2
L	Evaluation of debris removed	-	Yes	J, K	48	K	2500000	2
M	Search and rescue operations	Yes	-	Nil	72	C,D	7600000	5
N	Transportation of the sick and injured victims	Yes	-	Q	24	M	7000000	5
O	Distribution of government relief materials	Yes	-	R	72	N	30000000	5
P	Provision of a temporary shelter at a safe distant	Yes	-	Q	24	M	5000000	3
Q	Provision of temporary homes	-	Yes	P	24	M, N	20000000	3
R	Repairs of affected homes	-	Yes	Q	720	G, H	15000000	3
S	House damage survey	-	Yes	Nil	24	A, G	250000	5
T	Demolition of buildings disrupting major waterways	-	Yes	U,	72	S	3000000	3
U	Dredging of drainages and water sources	-	Yes	Nil	240	A, S	100000000	3
V	Removal of still water from drainages	Yes	-	S	72	U	5000000	4
W	Construction of temporary bridges.	-	Yes	P, Q	504	T	5000000	7
X	Replacement/ Repairs of power transformers	-	Yes	Y	120	A, G	15000000	7
Y	Installation of solar-powered street lights	-	Yes	X	120	A, X	6000000	5

*1 USD = ₦365

3.2 Network analysis and scheduling for PFRP

The network diagram for activities in PFRP as classified in Table 4 was constructed using the activity of arc convention as shown in Fig. 1. To construct a timetable for each restorative activity, PFRP was scheduled under the assumptions of time and resource constraints. Scheduling with time and resource constraints is equivalent to TCPSP and RCPSP, respectively. TCPSP and RCPSP-FS models were solved using CPM and priority rule-based scheduling (PRBS). PRBS consists of a schedule generation scheme (SGS) and a priority rule to rank activities. Serial SGS is a heuristic approach that constructs a feasible schedule without violating precedence/ resource constraints. The latest finish time as a priority rule was chosen because of its logical feasibility. The maximum number of supervisors (i.e. renewable resources) available for PFRP was assumed to be 9. The algorithm for CPM and SSGS was executed using Lingo software release 18.0.56. The schedule using SSGS is presented in Fig. 2.

3.3 Activity Time Probability Distribution

From the data collected, information on renewable resource demand for individual restorative activity was not provided. However, when renewable resources are fixed or constrained, the completion time for PFRP will be elongated because project activities will compete for finite resources during the project horizon.

To model the probabilistic nature of activity duration in PFRP due to estimation errors, Monte Carlo Simulation run (MCSRun) was used to obtain sets of variable activity duration. Since activity duration is counted in discrete values (i.e. days), a discrete distribution was assumed. The steps in MCSRun are (i) random number generation from the interval [0,1] (ii) construct a cumulative distribution function and (iii) replace DAPD with SAPD. A discrete distribution function with activity duration between 1 and 30 days' (30 days was the maximum processing time from activity information) was randomly generated with corresponding probability input for the 25 project activities (i.e. 30 simulation runs).

Each MCSRun presents a real project scenario where activity duration uncertainties were addressed. The values of time (CI, CRI) and schedule sensitivity (SSI) index were calculated using equations 1-3 adopted from Vanhoucke (2016).

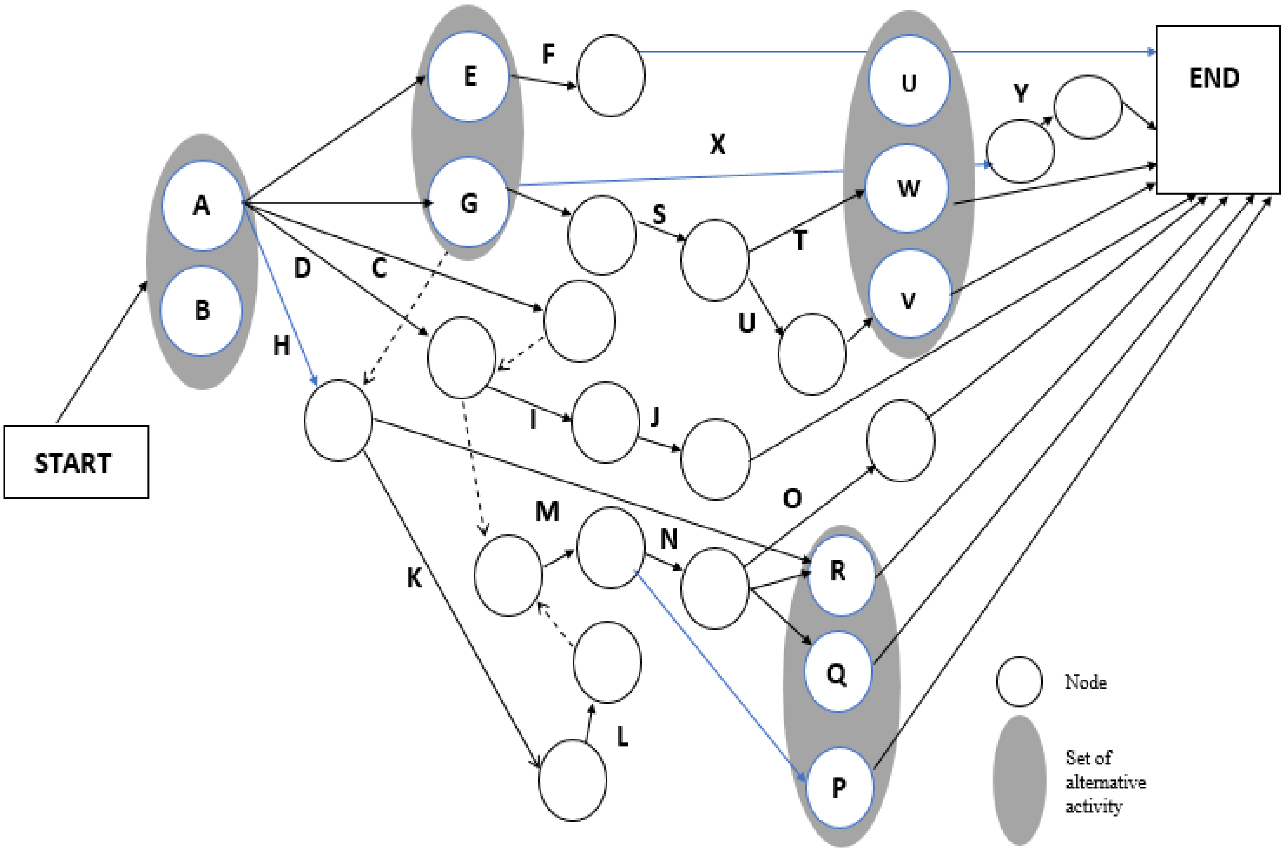


Fig. 1. Network diagram for PFRP

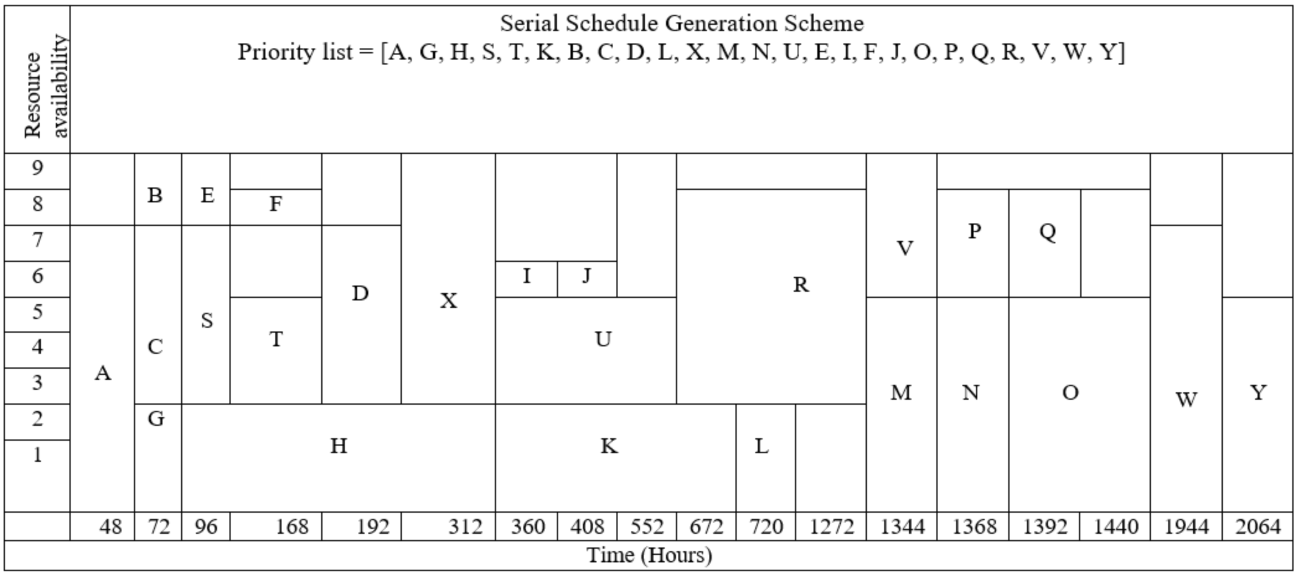


Fig. 2. Project schedule using serial schedule generation scheme for PFRP

$$\mathrm{CI}(i) = \Pr(\mathrm{tf}_i = 0) \quad (1)$$

$$\mathrm{CRI}\ (i) = \frac{\sum\{(SAPD-\overline{SAPD}*(SPCT-\overline{SPCT})\}}{\sqrt{\sum(SAPD-\overline{SAPD})^2*\sum(SPCT-\overline{SPCT})^2}} \quad (2)$$

$$\mathrm{SSI}\ (i) = \mathrm{CI}(i) * \frac{\sigma_{SAPD}}{\sigma_{SPCT}} \quad (3)$$

4. Results and Discussion

4.1 Activity categorisation

Twenty-five (25) restorative activities were identified as presented in Table 4. Fourteen (14) were categorized as compulsory and eleven (11) as non-compulsory, respectively. The set of compulsory activities include: A, B, C, D, F, G, H, I, J, K, M, N, O, P and V. The set of non-compulsory activities are E, L, Q, R, S, T, U, W, X and Y.

From the set of compulsory and non-compulsory activity, activities with alternative choices are B = {A}, E = {G}, G = {E}, L = {J, K}, N = {Q}, O = {R}, P = {Q}, Q = {P}, R = {Q}, T = {U, V, W}, V = {S}, W = {P, Q}, X = {Y} and Y = {X}.

Based on activity categorisation, it is obvious that rigid dependencies among restorative activities will change. New dependencies will reveal technological constraints between activities that are previously not linked by direct precedence relationships. For example, in Fig. 1, the choice between A and B is connected to activity 'start' (a dummy activity). Since activity 'start' is compulsory, then activity A and B will be compulsory.

4.2 Activity scheduling

From CPM, the schedule A-H-R consists of three restorative activities, A (flood area survey), H (clearing of debris) and R (repairs of affected homes) which is the longest path with a project completion time of 42 days (1008 hours). The completion time under a rigid project structure was achieved by the simultaneous availability of more than 9 supervisors. Also, a schedule with the absence of resource constraints is merely activity sequencing and too idealistic for flood events management. Furthermore, for a post-flood measures decision-maker, the inherent precedence relationship between activities may not allow the execution of life-threatening activities at the earliest start time. For example, activity N (transportation of the sick and injured victims) with a duration of 24 hours starts on day 32. The need to wait based on this schedule could resolve to loss of lives due to a rigid structure. From a flexible structure approach, the completion time was 86 days (2064 hours) as shown in Fig. 2. Although, the completion time was elongated because of resource restriction; however, 34 flexible paths were identified. These paths are sub-projects which can stand alone based on the severity of the flood incident. These paths were grouped based on similarities and summarized into 4 post-flood restorative measures under the following sub-headings: (I) removal of hazardous materials, (II) evacuation of injured persons, (III) provision of the flood warning system and technical facilities, and (IV) construction of shelter, homes and bridges.

The corresponding flexible path numbers for I, II, III and IV as presented in Table 5 are (1, 2, 3, 4); (5, 7, 8, 9, 10, 11,12, 13,14, 15, 16, 17, 18, 19, 20); (21, 22, 23, 24, 25,26, 27, 28) and (29, 30, 31, 32, 33, 34), respectively. A cursory look revealed that each path is standalone which allows a degree of freedom in activity scheduling. This freedom will resolve the effect of resource non- availability on activity scheduling which caused activities M (search and rescue operations) and N (Transportation of the sick and injured victims) to be pushed to a later date.

A flexible structure through a sub-project approach will make decision making effective and give insights on activity planning based on the degree of freedom available. Invariably, emergency officers will be able to review flood situations in real-time.

4.3 Time and Cost implications for alternative paths

Time obtained from network analysis, resource and cost characteristics for the individual path are presented in Table 5. As sub-projects, opportunities for adjustments and adaptation due to resource constraints (i.e. no of supervisors) can be realized. This adjustment can be observed from Fig. 2 with path A-H-R which can be completed in 53 days with limited supervisors. Also, network A-C-M-N-O with search, rescue, and transportation of injured persons to medical facilities, can be completed within 8 days or less if activities A and O are optional. Also, the efficient utilization of available funds can be realized. This corroborates the fact that flood events management is unique; therefore, not all the identified 25 activities are required to be executed at once.

Table 5. Time, resource and cost requirements for each flexible path

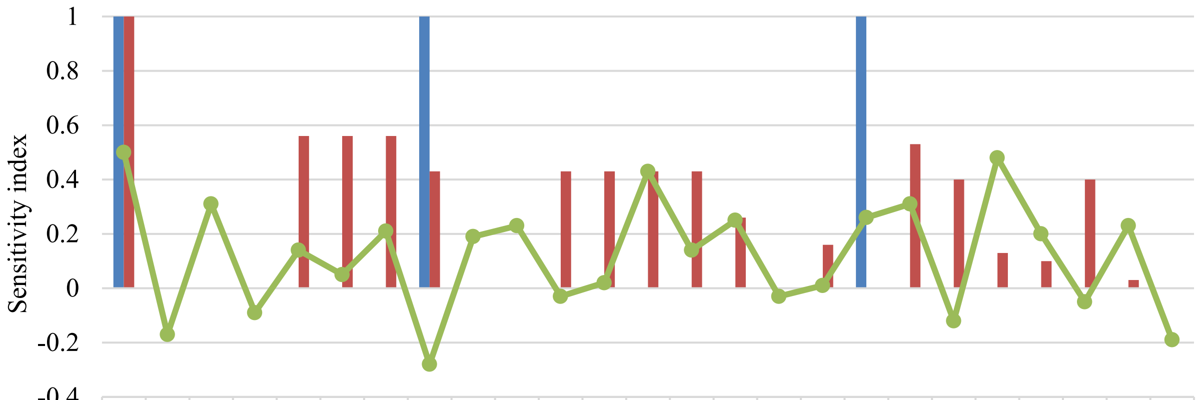
Path No.	Path activities	Time (days)	Maximum no of supervisors required	Cost (million)
1	A-C-I-J	6	7	8.4
2	A-D-I-J	7	7	10.4
3	B-C-I-J	7	7	5.4
4	B-D-I-J	7	7	7.4
5	A-D-M-N-O	8	7	51.6
6	A-C-M-N-O	8	7	49.6
7	A-H-K-L-M-N-R	63	7	38.7
8	A-H-K-L-M-N-O	36	7	53.7
9	A-D-M-N-Q	8	7	41.6
10	A-C-M-N-Q	8	7	39.6
11	A-G-K-L-M-N-O	27	7	53.7
12	A-G-K-L-M-N-Q	25	7	43.7
13	B-D-M-N-O	10	7	48.6
14	B-C-M-N-O	10	7	46.6
15	B-H-K-L-M-N-R	62	7	35.7
16	B-H-K-L-M-N-O	36	5	50.7
17	B-D-M-N-Q	8	7	38.6
18	B-C-M-N-Q	8	7	36.6
19	B-G-K-L-M-N-O	27	5	50.7
20	B-G-K-L-M-N-Q	25	5	40.7
21	A-E-F	6	2	10
22	A-G-X-Y	13	7	24.1
23	A-G-S-T-W	28	7	11.4
24	A-G-S-U-V	17	7	108.3
25	B-E-F	5	2	7
26	B-G-X-Y	13	7	21.1
27	B-G-S-T-W	28	7	8.4
28	B-G-S-U-V	17	4	105.4
29	A-H-R	42	7	18.1
30	A-G-R	33	7	18.1
31	A-H-K-L-M-P	33	7	21.7
32	B-H-K-L-M-P	33	5	18.7
33	B-H-R	42	7	15.1
34	B-G-R	33	7	15.1

For a post-flood event manager, understanding the influence of alternative activities on project completion time can assist in decision making. This implies that a set of alternative activities can increase, decrease, or no effect on completion time. From Table 5, paths 1 and 2 with two different choices (C and D) increases PCT from 6 to 7 days, this decision can be viewed as a setback. Similarly, network paths (in pairs) with no effect (i.e. unchanged) on the value of completion time include: (3,4), (5,6), (9,10), (13,14), (17,18), (22,26), (23,27), (24, 28), (29,33), (30,34) and (31,32). In contrast, paths (in pairs) with one different choice leading to reduction in completion time are (7,8), (11,12), (15,16), (19, 20) and (21, 25). Improvement in project completion time is achievable when the right choices are considered.

4.4 Time sensitivity measures

Time sensitivity measures were obtained to understand the impact of each simulated activity processing duration (SAPD) on its simulated project completion time (SPCT) as displayed in Fig. 3. Activity A, H and R with critical path index (CP) of (1,1,1) obtained under the assumption of unlimited resources have criticality index (CI) of (1,0.43,0). This implied that for activity H and R under uncertain activity processing time, the probability to remain on the longest path had been reduced by 57 and 100%, respectively. This uncertainty could be attributed to estimation errors associated with the determination of most project parameters.

Likewise, activities E, F, G, K, L, M, N, O, Q, S, T, U, V, W and X, with zero CP under unlimited resources assumptions have the potential of being on the longest path when a schedule risk analysis (SRA) was performed. For instance, using SAPD obtained under simulation run 1, network path B-H-K-L-M-N-R returned the longest path of 103 days with K, L and M becoming sensitive with CI value of 0.43 for each activity (see Fig. 3). Also, network path B-G-S-T-W returned the longest path of 102 days. In this case, G, S, T, and W attained sensitivity status with CI of 0.56, 0.53, 0.40 and 0.40, respectively. In contrast, N from the schedule (B-H-K-L-M-N-R) attained a sensitive status; however, its CI is zero (see Fig. 3). Theoretically, it corroborates concerns from the literature on the counter-intuitive results that may be obtained from different project scenarios using schedule risk analysis. Hence the need to have a large number of simulation runs to increase the reliability of the results.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
CP	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
CI (i)	1	0	0	0	0.6	0.6	0.6	0.4	0	0	0.4	0.4	0.4	0	0	0	0	0	0.5	0.4	0.1	0.1	0.4	0	0
CRI (i)	0.5	-0	0.3	-0	0.1	0.1	0.2	-0	0.2	0.2	-0	0	0.4	0.1	0.3	-0	0	0.3	0.3	-0	0.5	0.2	-0	0.2	-0

Restorative activities

Fig. 3. Time sensitivity measures CI and CRI for twenty-five (25) restorative activities

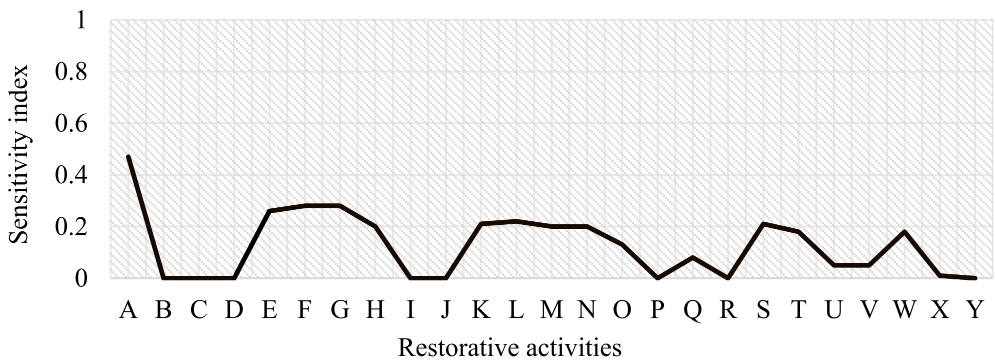


Fig. 4. Schedule sensitivity index(SSI) for twenty-five (25) restorative activities

On the degree of linear dependency (CRI) between SAPD and SPCT, a low positive correlation was recorded for all the activities except B, D, H, K, P, T, W and Y which has a negative correlation. A CRI index of 0.5 indicates a strong association between SAPD and SPCT for activity A; however, this association does not suggest causation between SAPD and SPCT. CRI index for a decision-maker can assist to distinguish between sensitive and insensitive activities. Theoretically, this result confirmed comments that the relationship between activity duration and total project duration often follows a non-linear relationship. For example, activity H, K and R with long processing time has a non- increasing relationship with project completion time except R with a low positive correlation when compared with project completion time.

Nevertheless, CI and CRI indices will assist a post-flood decision-maker to view activity from a degree of sensitivity rather than from the viewpoint of certainty.

4.5 Schedule sensitivity index (SSI)

SSI for PFRP is displayed in Fig. 4. The index ranges from 0 to 47%. For activities C, D, I, J, P and Y that were classified as compulsory (i.e. sensitive) returned zero SSI. A zero SSI infers that activities can be re-modelled as non-compulsory e.g. activity I and J.

5 Conclusion

In this study, it was established that the structure which defines the technological and precedence relationship among activities in most real-life projects are rigid. The resource-constrained project scheduling problem with a flexible project structure simultaneously considers alternative activity for processing and decisions on project scheduling.

This framework was applied to a post-flood restoration project due to the impact of flexibility in project management. From the application, 34 flexible network paths were identified and categorized into 4 flood events measures. From the viewpoint of scheduling, the relationship between different activity choices and project completion time provided insights on possible improvements or setbacks. The sensitive nature of the duration of restorative activities due to estimation error was modelled using Monte Carlo simulation. Based on these results, a flexible project structure can respond to changing circumstances during post-flood restoration efforts which allow more degree of freedom in activity scheduling, flood events measure(s) and cost alternatives.

Although, this research offers contribution on the applicability of resource-constrained projects with flexible project structure to flood events management. Further research areas include generating random networks to determine the complex nature of PFRP instances, the use of other schedule generation schemes, generating different priority lists and solving the problem using meta-heuristics.

References

ADB Performance Evaluation Report. (2006). *Bangladesh: Flood Damage Rehabilitation Project Number PPE: BAN 32501*. Retrieved from https://www.adb.org/sites/default/files/evaluation-document/35126/files/32501-ban-pper.pdf on August 3, 2020

Artigues, C., Leus, R., and Nobibon, F. A. (2013). Robust optimization for resource constrained project scheduling with uncertain activity durations. *Flexible Services and Manufacturing Journal*, 25, 175-205.

Agbola, B. S., Ajayi, O., Taiwo, O. J., and Wahab, B. W. (2012). The August 2011 flood in Ibadan, Nigeria: Anthropogenic cause and consequences. *International Journal of Disaster Risk Science,* 3(4), 207-217.

Annegret, H. T., Sarah, K., Heidi, K., Christian, K., Michael, K., Bernhard, M., Meike, M., Antje, O., Theresia, P., Sebastian, P., and Kai, S. (2013). Review of the flood risk management system in Germany after major flood in 2013. *Ecology and Society,* 21(2).

Bernardes, E. S. and Hanna, M. D (2009). A theoretical review of flexibility, agility and responsiveness in the operations management literature: Towards a conceptual definition of customer responsiveness. *International Journal of Operations & Production Management*, 29 (1), 31-53.

Correla, F. N., Forham, M., Saraiva, M. D., and Bernarrdo, F. (1998). Flood hazard assessment and management: Interface with the public. *Water Resource Management,* 12, 209-227.

Deltares. (2010). *Flood Risk Management*. Retrieved from http://www.deltares.nl on August 3, 2020

Demeulemeester, E. L. and Herroelen, W. S. (2002). *Project scheduling: A research handbook.* Boston. Kluwer Academic Publisher, 169-174.

Engel, H. (2004). The flood event 2002 in the Elber River Basin: Causes of the flood, its course, statistical assessment and flood damages. *Houille Blanche,* 6, 33-36.

Gautum, K. P. and Van der Hoek, E. E. (2003). Literature study on environmental impact of floods. *Delft Cluster-Publication Netherlands*, DC 1-233-13, 6-8.

Hartmann, S. and Briskorn, D. (2010). A survey of variants and extensions of the resource-constrained project scheduling problems. *European Journal of Operational Research,* 207, 1-15.

Jouannic, G., Crozier, D., Chloe, T. D. M., Kolli, Z., Arki, F., Matagne, E., Arbizzi, S., and Bomperin, L. (2016). Post-disaster recovery: How to encourage the emergency of economic and social dynamics to improve resilience? *FLOODrisk 2016 - 3rd European Conference on Flood Risk Management.*

Kellenbrink, C. and Helber, S. (2015). Scheduling resource-constrained projects with flexible project structure. *European Journal of Operational Research,* 246(2), 379-391.

Kikwasi, G. J. (2012). Cause and effects of delays and disruptions in construction projects in Tanzania. *Australasian Journal of Construction Economics and Building Conference Series,* 1(2), 52-59.

Miltiadis, A. B. and Lazar, P. (2010). Industrial project management: a handbook of planning, scheduling and evaluation techniques.

Möhring, R. H. (1984). Minimizing costs of resource requirements in project networks subject to a fixed completion time. *Operations Research,* 32(1), 89-120.

Nepal Flood (2017). *Post Flood Recovery Needs Assessment*. Retrieved from https://www.np.undp.org/content/nepal/en/home/library/crisis_prevention_and_recovery/post-flood-recovery-needs-assessment.html on August 3, 2020

Odedairo, B. O. (2016). *Development of scheduling heuristic for the resource constrained project management problem with idleness cost*. Unpublished

thesis submitted to obtain doctor of philosophy in the faculty of technology, University of Ibadan.
Odedairo, B. O. and Oladokun, V. O. (2018). Development of a schedule cost model for a resource constrained project that incorporates idleness. *International Conference on Project Management and Scheduling (PMS '18),* Rome, Italy, 169-174.
Odedairo, B. O. and Nwabuokie, N. (2018). Framework for operational performance measurements in small and medium scale industries using discrete event simulation approach. *Engineering, Technology and Applied Science Research,* 8(4), 3103-3107.
Saidu, I. and Dharmasiri, M. L. (2015). Flood risk inevitability and flood risk management in urban areas: a review. *Journal of Geography and Regional Planning,* 8(8), 205-209.
Samuel, A., Phebe, O., and Herath, M. P. C. (2015). Flood risk management in Ghana; a case study in Accra 2013. *Journal of Advances in Applied Science Research,* 6(4), 196-201.
Servranckx, T. and Vanhoucke, M. (2018). Resource constrained project scheduling with alternative project structures. *International Conference on Project Management and Scheduling (PMS '18),* Rome, Italy, 213-216.
Shrestha, A. B., Chapag, P. S., and Thapa, R. (2011). Flash flood risk management: A Training of the trainers manual. *International Centre for Integrated Mountain Development*. Kathmandu, Nepal.
Simonovic, S. P. and Carson, R. W. (2003). Flooding in the Red River Basin-Lessons from post flood activities. *Natural Hazards*, 28, 345-365.
Smith, K. (2013) Environmental Hazards: Assessing Risk and Reducing Disaster, Sixth Ed. *Routledge*. New York.
Thampapillai, D. J. and Musgrave, W. F. (1985). Flood damage mitigation: a review of structural and non-structural measures and alternative decision frameworks. *Water Resources,* 21. 411-424.
Thieken, A. H., Petrow, T., Kreibich, H., and Merz, B. (2006). Insurability and mitigation of flood losses in private households in Germany. *Risk Analysis,* 26(2). 383-395.
Thieken, A. H., Kienzler, S., Kreibich, H., Kuhlicke, C., Kunz, M., Muhr, B., Muller, M., Otto, A., Petrow, T., Pisi, S., and Schroter, K. (2013). Review of the flood risk management system in Germany after major flood in 2013. *Ecology and Society,* 21(2), 51.
Ulbrich, U., Brucher, T., Fink, A. H., Leckebusch, G. C., Kruger, A., and Pinto, J. G. (2003). The central European floods of August 2002: Part 1, *Rainfall Periods and Flood Development Weather,* 58, 371-377.
UNHabitat, Pakistan Settlements Flood Recovery Project (PSFRP). Retrieved from http://unhabitat.org.ir/wp-content/uploads/2019/04/PSFRP-Report-June-2015-final.pdf on August 3, 2020
Vanguard News (2017). *Floods devastate Ibadan again as perennial challenge returns*. Retrieved from http://www. Vanguardngr.com/2017/06/floods-devastate-ibadan-perennial-challenge-returns/amp on August 3, 2020.
Vanhoucke, M. (2016). Integrated Project Management Sourcebook: A Technical Guide to Project Scheduling, Risk and Control. *Springer International Publishing*, 126-150. Switzerland.
Vanhouwaert, G. (2018). *Flexible project structures in resource-constrained project scheduling: a case study*. Unpublished Dissertation submitted to obtain the degree of Master of Science in Business Engineering, University of Ghent.

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