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Project Complexity Indices based on Topology Features

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***Abstract*—**The heuristic decision rules used for project scheduling will vary depending upon the project's size, complexity, duration, personnel, and owner requirements. The concept of project complexity has received little detailed attention. The need to differentiate between easy and hard problem instances and the interest in isolating the fundamental factors that determine the computing effort required by these procedures inspired a number of researchers to develop various complexity measures.

In this study, the most common measures of project complexity are presented. A new measure of project complexity is developed. The main privilege of the proposed measure is that, it considers size, shape and logic characteristics, time characteristics, resource demands and availability characteristics as well as number of critical activities and critical paths. The degree of sensitivity of the proposed measure for complexity of project networks has been tested and evaluated against the other measures of complexity of the considered fifty project networks under consideration in the current study. The developed measure showed more sensitivity to the changes in the network data and gives accurate quantified results when comparing the complexities of networks.

***Keywords*—**Activity networks, Complexity index, Network complexity measure, Network topology, Project Network.

I. INTRODUCTION AND BACKGROUND

PROJECT complexity is often recognized in a general way, but not completely understood by everyone.

Just the term "complexity" causes some degree of difficulty because of the different interpretations given the definition and perhaps a person's experiences and training. Exploring the fundamental meaning of "complex" is helpful in establishing a foundation from which to build. "Complex" comes from the Latin word *complexus*, meaning entwined or twisted together. *Complexus* is also defined as an aggregate of parts. Complex can be interpreted as an item having two or more components – or two or more variables. Synonyms for complex include complicated, intricate, involved, tangled, and knotty [1]. Whereas all projects are complex to some degree, there is perhaps a range of complexity that needs to be assessed prior to accepting the project to understand the degree of difficulty that will be encountered. Assessing the complexity can give information for planning and anticipated actions by which to address the various situations. Lacking that information, allows the project to continue to address complexity as it is discovered during the work cycle. Projects have two primary areas for complexity – the technical complexity aspects of the project with the degree of difficulty in building the project and the business scope or management complexity aspects such as schedule, cost, risk, and communications.

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II. TECHNICAL COMPLEXITY

A. Technical Complexity

Technical scope of the project and service may be viewed as creating a specification that leads to a design to meet the client's needs. Some characteristics such as number of pieces, parts, components, subassemblies, and assemblies to the project, number of technologies involved may represents technical complexity while items may be related to the industry, type of project, and discipline rather than a general listing of items that can cause complexity as well as the degree of complexity.

B. Management Complexity

Management complexity includes the business aspects of the project, staff, relationships of the project to others, and project organization to name a few. There are many variables that can add complexity to the management of a project. Some characteristics such as financial arrangements that provide a smooth flow of cash to fund the project as the need for dollar resources occurs. The simplest arrangement is to have an available fund to tap as the project's needs are realized. The most complicated or complex arrangement might be funding from several different sources without specific time commitments as to when funds will be available. Design of the management structure should be straight forward with only the necessary managers involved for simplicity. Project partnerships between two or more organizations increase the complexity and possibly delays critical decisions to move the project forward. A steering committee may be appointed to make decisions on major projects, which may or may not add complexity. Schedules that lack sufficient detail to guide the project can add complexity without any derived benefit. A schedule that is too detailed can create an environment whereby the staff relies on it solely to guide its actions without thought of consequences. On the other hand, a schedule that is general in nature may not provide critical guidance. Complexity in this case may result from too much detail or not enough detail. Staffing a project with the proper skills and proper number of individuals at the right time is the simplest solution. Complexity increases when the right skills are not available in the required number at the required time. In some instances, it may be that only a few critical skills are needed for a specified period of time. The lack of these skills complicates getting the work accomplished to the proper performance criteria. Project organizational design should focus on the work to be performed. Organizational complexity increases as the design changes during the course of the project work and new staff is assigned. Whereas there will be changes to staff for a variety of reasons, new functions and arbitrary changes complicate the efficiency of the organization. Organizational interfaces add to complexity when the number exceeds three external parties. The simplest form of interface is when the project manager reports to a single senior manager and works with the client. Each additional relationship adds another dimension to the situation. As a matter of fact and based on the presented scenario of complexity aspects, both the technical and management complexity have a great influence on the project scheduling process and consequently on the project objectives success. Hence finding a scientific base for the complexity identification of the project is considered as a must issue in order to determine the best suitable scheduling procedure or algorithm for project execution. This goal is considered as main objective of the current research.

C. Complexity and Project Management

The construction process may be considered the most complex undertaking in any industry. However, the construction industry has displayed great difficulty in coping with the increasing complexity of major construction projects. Therefore an understanding of project complexity and how it might be managed is of significant importance.

Certain project characteristics provide a basis for determining the appropriate managerial actions required to complete a project successfully. Complexity is one such critical project dimension. It is widely observed; practitioners frequently describe their projects as simple or complex when they are discussing management issues. This indicates a practical acceptance that complexity makes a difference to the management of projects. It is not surprising that complex projects demand an exceptional level of management and that the application of conventional systems developed for ordinary projects have been found to be inappropriate for complex projects. The importance of complexity to the project management process is widely acknowledged, for example:

- Project complexity helps determine planning, co-ordination and control requirements.
- Project complexity hinders the clear identification of goals and objectives of major projects.
- Complexity is an important criteria in the selection of an appropriate project organizational form.
- Project complexity influences the selection of project inputs, e.g. the expertise and experience requirements of management personnel.
- Complexity is frequently used as a criterion in the selection of a suitable project procurement arrangement.
- Complexity affects the project objectives of time, cost and quality. Broadly, the higher the project complexity the greater the time and cost.

D. Measuring Complexity and Scheduling Procedures

No single scheduling procedure is computationally feasible for the large and complex projects and the success of a certain specified algorithms or heuristics depend mainly on the project characteristics. Since most success to date has been found in the application of heuristic techniques, research on heuristic solution procedures is still popular. The search for measuring criteria that verify the effectiveness of the proposed heuristic solution procedure is a must. The measuring criteria are classified into complexity measures and performance measures. Performance measures are categorized into performance measures for constrained resource problem, performance measures for unconstrained resource problem, and performance measures for both of them [2]. The scheduling algorithms and heuristic decision rules used for project scheduling vary with the project's size, complexity, duration, personnel, and owner requirements. No simple heuristic decision criterion can be applied and perform well for different project network topologies, complexities, characteristics, and resource levels; where the project configurations play a very important and vital role in the application success of a certain specified heuristic decision criterion in scheduling [2]. One possible measure of network size; is the total number of nodes contained in the network, including the necessary single beginning and single ending nodes. Network shape can be specified on the basis of three separate factors; a measure of network length, a measure of network width, and a measure of the relationship of length to width. Time-related measures such as average activity duration, variance in duration, and critical path duration are used to specify networks. Also, the total slack contained in the network and the total free slack are important measures. Strictly speaking, each of these measures is a function of network logic and might be included in the first class of measures, Davis [3]. The measurement of "complexity" of activity networks is needed to estimate the computing requirements and/or to validly compare alternative heuristic procedure. There are several quantitative and qualitative factors with unknown interactions that are present in project networks. Measure of project complexity should be used as a relative measure of comparison rather than as an absolute indication of the difficulty involved in scheduling a given project. Evidently, a choice between two proposed algorithms, or the determination of the efficiency of a particular algorithm, would be greatly facilitated if there exists a measure of network complexity. This would eliminate any possible bias in the conclusions regarding the efficiency of a particular algorithm relative to others by ensuring that the algorithm is evaluated at several points in the "range of complexity".

III. RELATED WORK

Any complex project consists of a number of activities which are carried out in some specified precedence order. One of the factors that is considered is in minimizing the project completion, time. The computation of the optimum project completion time is proportional to the number of edges, including dummy activities. When an activity-on-arc (AOA) project network is to be constructed, one typically seeks to minimize the number of dummy arcs. Recent investigations have shown, however, that the computational effort of many network-oriented project management techniques depends strongly on the so-called *complexity index* (*CI*) of a network. Kamburowski et. al. [4], showed other justifications for minimizing the CI rather than the number of dummy arcs. They also presented a polynomial time algorithm for constructing an (AOA) network with the minimum (CI) in the class of all (AOA) networks having the minimum number of nodes.

A framework that measures complexity within the various stages of a project, together with a measure of complexity for the complete project lifecycle in the form of a complexity index (CI) is presented by Nassar et al [5]. In essence, the framework provides the project manager with a tool that helps to identify the possible manifestation of complexity within the project process and the ability to plan accordingly to minimize its impact. This framework was developed and evaluated based on some bench mark engineering design projects.

Several factors contribute to the complexity of project schedules, including the number of activities, the level of detail, and the shape of the project network have been introduced by Nassar et al [6]. This paper presents a measure that assesses the complexity of project schedules in terms of the connectivity of the activities. Unlike similar complexity measures, the proposed complexity measure does not consider redundant relationships in the project's schedule. In addition, the measure is expressed as a percentage and therefore has the advantage of being intuitively understood by project managers. The measure considers the degree of interrelationships between the activities in the project's schedule. The measure has been implemented in a computerized tool to help managers assess the complexity of their projects. The tool is developed as an add-in to popular commercial scheduling software like MS Project.

Martin et al [7] proposed an algorithm for investigation the IS project management practices related to projects of varying size and complexity across diverse industries. Survey data on a broad range of project management issues was collected from 129 IS project managers. The relationships between project size and complexity with 13 project management practices and 3 project performance measures were analyzed. In addition, the influence of a PMO on the use of standardized project management practices and project performance was empirically tested. The findings suggest that IS project size influences budget and project quality, while project complexity influences the use of specific project management practices. The PMO is empirically linked to project budget.

According to Kaimann et. al. [8], the degree of complexity of a critical path network may be classified by calculating a Coefficient of Network Complexity. It is defined as the quotient of activities squared divided by events or preceding work items squared divided by work items. Three distinct contributions are offered. First, the CNC may serve as an indicator of the attention spent in planning the project. Second, the CNC may be used to derive a predictor of network computer processing time. Third, the CNC value suggests the appropriate processing scheme.

A large number of optimal and suboptimal procedures have been developed by De Reyck B. and Herroelen [9], for solving combinatorial problems modeled as activity networks. They investigated the relation between the hardness of a problem instance and the topological structure of its underlying network, as measured by the complexity index. They demonstrated through a series of experiments that the complexity index, defined as the minimum number of node reductions necessary to transform a general activity network to a series-parallel network, plays an important role in predicting the computing effort needed to solve easy and hard instances of the multiple resource-constrained project scheduling problems and the discrete time/cost trade-off problem.

Pich, et. al. [10], developed a model of a project as a payoff function that depends on the state of the world and the choice of a sequence of actions. An underlying probability space represents available information about the state of the world. Interactions among actions and states of the world determine the complexity of the payoff function. Activities are endogenous, in that they are the result of a policy that maximizes the expected project payoff. They identified three fundamental project management strategies which show that; classic project management methods emphasize adequate information and instructionism, and demonstrate how modern methods fit into the three fundamental strategies. The appropriate strategy is contingent on the type of uncertainty present and the complexity of the project payoff function.

Baccarini [11], reviewed the literature on project complexity relevant to project management, with emphasis towards the construction industry. The paper proposes that project complexity can be defined in terms of differentiation and interdependency and that it is managed by integration.

IV. COMPLEXITY MEASURES IN ACTIVITY NETWORK

A. *Existing Measures of Network Complexity*

The measurement of the “complexity” of activity networks seems to be needed in order to estimate the computing requirements and/or to validly compare alternative heuristic procedures. There is always a debate as to whether or not the complexity of a project can be accurately quantified. There are several quantitative and qualitative factors with unknown interactions that are present in any project network. As a result, any measure of project complexity should be used as a relative measure of comparison rather than as an absolute indication of the difficulty involved in scheduling a given project [12].

Evidently, a choice between two proposed algorithms, or the determination of the efficiency of a particular algorithm, would be greatly facilitated if there exists a measure of network complexity. This would eliminate any possible bias in the conclusions regarding the efficiency of a particular algorithm relative to others by ensuring that the algorithm is evaluated at several points in the "range of complexity". Table I gives a bird's eye view of the proposed measures mentioned in [12], [13].

TABLE I
SUMMARY OF MEASURES OF NETWORK COMPLEXITY

Network Complexity Measure	Suggested By
Coefficient of Network Complexity CNC (P) = A/N	Pascoe
CNC (D) = 2(A – N + 1) / (N-1) (N-2)	Davies
CNC (K) = A^2/N	Kaimann
Total Activity Density-T-Density ∑ Max {0, number of predecessor activities - number of successor activities}	Johnson
Average Activity Density (T – density) / N	Patterson
$CNC(B) = (\frac{P}{CP})\{(1 - \frac{1}{A})\sum_{i=1}^{A} ti\,(\frac{\sum^{A} tir_{ij}}{RA_j})\}$	Badiru

CNC = Coefficient of network complexity.
A = Number of activities in the network.
N = Number of nodes in the network.
ti = Expected duration for activity(i).
R = Number of resource types.
ri = Units of resource type j required by activity(i).
RAj = Maximum units of resource type j available.
P = Maximum number of immediate predecessors in the network.
CP = Project duration with no resource constraint

The suggested measures of Pascoe, Davies and Kaimann [14], [15], [8], rely totally on the count of the activities and nodes in the network. Since it is easy to construct networks of equal number of arcs and nodes but with varying degrees of difficulty in analysis, we fail to see how these measures can discriminate among them.

The total activity density, T-density as a coefficient of network complexity which is suggested by Johnson [16] considers only the maximum difference between the predecessor and successor activities allover the network nodes and ignoring all the other network characteristics, (size, shape, duration, resources,…. etc.).

The same remark can be focused for the average activity density as a coefficient of network complexity which is developed by Patterson [17]. The quantitative measure of complexity of a project network that is presented by Badriu [12] is more sensitive than the other measures. In this complexity measure, the maximum number of immediate processors (P) is a multiplicative factor that increases the complexity and potential for bottlenecks in a project network. The (1 – (1/A)) is a fractional measure (between 0 and 1) that indicates the time intensity or work content of the project. As (A) increases, the quantity (1-(1/A)) increases, and a larger fraction of the total time requirement sum of (ti) is charged to the network complexity. Conversely, as (A) decreases, the network complexity decreases proportionately with total time requirement. The sum of (ti rij) indicates the time-based consumption of a given resource type j relative to the maximum availability. The term is summed over all the different resource types. Having (CP) duration in the denominator, it helps to express the complexity as a dimension less quantity by canceling out the time units in the numerator. In addition, it gives the network complexity per unit of total project duration. As it has been focused that this measure handles most of the project network parameters affecting its complexity.

B. Proposed Complexity Measures

In the current study the proposed measures consider the number of critical activities, the number of critical paths, the time of the activities, the resource types and the resource availability for each resource type. However these measures are represented in the equations listed below. In order to make these measures more sensitive for project complexity some additional parameters are considered in the evaluation of the proposed complexity measures. These parameters are the number of critical activities, number of critical paths, the ratio of critical activities to the total number of project activities, the resource types, the available level of the resource types, and the length of the critical path. As it exhibited that, these considered parameters have a great influence on both the project schedule and project success. The proposed measures are defined as:

$$CNC\ (PR1) = [\frac{W}{(1-Ac/A)}][\frac{P}{CP}\{(1-\frac{1}{A})\sum_{i=1}^{A} ti + \sum_{j=1}^{R} (\frac{\sum^{A} tir_{ij}}{RA_j})\}] \quad (1)$$

$$CNC\ (PR2) = Ac/A \quad (2)$$

$$CNC(PR3) = [\frac{1}{(1-Ac/A)}][\frac{P}{CP}\{(1-\frac{1}{A})\sum_{i=1}^{A} ti + \sum_{j=1}^{R} (\frac{\sum^{A} tir_{ij}}{RA_j})\}] \quad (3)$$

Where:

W = number of critical paths in the network.
Ac = number of critical activities in the network.
A = number of activities in the network.

V. RESULTS AND DISCUSSION

The In this study 50 project data set, that are considered as a bench mark problems [2], has been taken in the current study. The complexity measures presented by Pascoe, Davies, Kaimann, Badriu, in addition to those presented by the current work have been evaluated and presented for the considered 50 project data set and presented in Table II.

TABLE II
THE PROPOSED MEASURES VERSUS OTHER MEASURES

PN	P1	P2	P3	P4	PR1	PR2	PR3
1	1.43	0.27	14.29	10.15	16.92	0.4	16.92
2	1.63	0.29	21.13	6.22	40.46	0.69	20.22
3	1.63	0.29	21.13	8.92	12.88	0.31	12.88
4	1.33	0.14	16	7.17	14.33	0.5	14.34
5	1.22	0.11	13.44	4.19	11.53	0.64	11.52
6	1.22	0.11	13.44	6.48	8.91	0.27	8.91
7	1.67	0.25	25	11.61	34.84	0.33	17.42
8	1.22	0.11	13.44	9.16	14.4	0.36	14.39
9	1.2	0.08	14.4	7.74	15.47	0.5	15.48
10	1.5	0.17	22.5	8.27	13.79	0.4	13.78
11	1.18	0.07	15.36	9.27	15.07	0.38	15.06
12	1.36	0.11	20.45	6.1	36.59	0.67	18.3
13	1.25	0.07	18.75	6.92	12.97	0.47	12.98
14	1.2	0.04	21.6	6.79	11.11	0.39	11.11
15	1.5	0.09	36	8.98	14.36	0.38	14.37
16	1.24	0.04	25.94	9.4	17.94	0.48	17.95
17	1.29	0.05	28.47	8.74	19.22	0.55	19.23
18	1.26	0.04	30.32	6.51	14.21	0.54	14.2
19	1.4	0.05	39.2	10.52	36.81	0.43	18.41
20	1.29	0.03	40.04	16.69	51.74	0.35	25.87
21	1.78	0.08	73.09	17.05	53.78	0.37	26.89
22	1.25	0.03	37.5	6.97	13.06	0.47	13.07
23	1.36	0.03	51.57	14.26	18.69	0.24	18.69
24	1.34	0.03	57.78	7.91	12.15	0.35	12.15
25	1.35	0.02	72.9	16.94	24.07	0.3	24.07
26	1.8	0.25	32.4	11.81	17.71	0.33	17.72
27	1.25	0.14	12.5	7.64	12.74	0.4	12.73
28	1.3	0.11	16.9	9.36	40.56	0.54	20.28
29	1.2	0.08	14.4	7.71	37	0.58	18.5
30	1.5	0.24	18	14.66	39.1	0.25	19.55
31	1.06	0.02	19.06	9.99	14.99	0.33	14.99
32	1.2	0.04	21.6	6.75	11.05	0.39	11.05
33	1.48	0.05	54.76	11.78	16.76	0.3	16.76
34	1.33	0.04	42.67	13.89	17.1	0.19	17.1
35	1.17	0.01	49	9.78	17.12	0.43	17.12
36	1.56	0.08	43.56	17.62	58.03	0.39	29.02
37	1.48	0.05	50.26	22.92	28.86	0.21	28.86
38	1.44	0.08	33.06	13.72	17.53	0.22	17.53
39	1.76	0.05	114.1	21.72	26.15	0.17	26.14
40	1.5	0.09	36	15.44	49.41	0.38	24.7
41	1.38	0.04	49.85	20.97	98.46	0.36	32.82
42	1.53	0.04	70.53	15.31	84.53	0.46	28.17
43	1.36	0.04	40.91	9.16	15.26	0.4	15.27
44	1.18	0.07	15.36	11.34	49.13	0.54	24.57
45	1.38	0.19	15.13	8.61	15.78	0.45	15.79
46	1.2	0.08	14.4	9.08	43.58	0.58	21.79
47	1.2	0.04	21.6	10.82	17.71	0.39	17.71
48	1.33	0.05	32	5.42	8.13	0.33	8.13
49	1.31	0.08	22.23	6.52	13.86	0.53	13.86
50	1.41	0.05	43.68	10.49	14.14	0.26	14.14

PN : Project number
P1 : Complexity measure by Pascoe
P2 : Complexity measure by Davies
P3 : Complexity measure by Kaimann
P4 : Complexity measure by Badiru
PR1 : First proposed complexity measure
PR2 : Second proposed complexity measure
PR3 : Third proposed complexity measure

The number of nodes exists in this data set for the projects under consideration ranges from 8 to 40 nodes. The number of activities ranges from 10 activities to 65 activities. The number of critical activities in the project ranges from 3 critical activities to 21 critical activities. The maximum number of critical paths exist in the project are 3 paths. The critical path length ranges from 10 units of time to 124 units of time.

Table III list these measures in an ascending order for the same measures. Focusing on the resulted data in both the two tables (Table II and Table III) will find that there is a general variation trend of the new proposed complexity measures. This trend of variation for the proposed measures is consistent with the other complexity measures such as Pascoe, Davies, Kaimann, and Badriu, where the increasing or decreasing in the proposed measures will attached with increasing or decreasing of the other measures respectively. Also the proposed measures are more sensitive than the other measures in evaluating the project' complexity where both the critical activities, the critical paths, number of critical activities to the total number of project activities, the length of critical path, and resource types and their availability are considered in the evaluation process. Also, the proposed measures of complexity will be more sensitive to the changes in the network data and will give accurate quantified results when comparing the complexities of networks. When the number of critical paths in network (W) increases the complexity of network will be increased, also; as the number of critical activities in the network (Ac) increase the complexity of network will be increased.

TABLE III
THE ARRANGED PROPOSED MEASURED

PN	PR1	PN	PR2	PN	PR3
48	8.13	39	0.17	48	8.13
6	8.91	34	0.19	6	8.91
32	11.05	37	0.21	32	11.05
14	11.11	38	0.22	14	11.11
5	11.53	23	0.24	5	11.52
24	12.15	30	0.25	24	12.15
27	12.74	50	0.26	27	12.73
3	12.88	6	0.27	3	12.88
13	12.97	25	0.3	13	12.98
22	13.06	33	0.3	22	13.07
10	13.79	3	0.31	10	13.78
49	13.86	7	0.33	49	13.86
50	14.14	26	0.33	50	14.14
18	14.21	31	0.33	18	14.2
4	14.33	48	0.33	4	14.34
15	14.36	20	0.35	15	14.37
8	14.4	24	0.35	8	14.39
31	14.99	8	0.36	31	14.99
11	15.07	41	0.36	11	15.06
43	15.26	21	0.37	43	15.27
9	15.47	11	0.38	9	15.48
45	15.78	15	0.38	45	15.79
33	16.76	40	0.38	33	16.76
1	16.92	14	0.39	1	16.92
34	17.1	32	0.39	34	17.1
35	17.12	36	0.39	35	17.12
38	17.53	47	0.39	7	17.42
26	17.71	1	0.4	38	17.53
47	17.71	10	0.4	47	17.71
16	17.94	27	0.4	26	17.72
23	18.69	43	0.4	16	17.95
17	19.22	19	0.43	12	18.3
25	24.07	35	0.43	19	18.41
39	26.15	45	0.45	29	18.5
37	28.86	42	0.46	23	18.69
7	34.84	13	0.47	17	19.23
12	36.59	22	0.47	30	19.55
19	36.81	16	0.48	2	20.22
29	37	4	0.5	28	20.28
30	39.1	9	0.5	46	21.79
2	40.46	49	0.53	25	24.07
28	40.56	18	0.54	44	24.57

46	43.58	28	0.54	40	24.7
44	49.13	44	0.54	20	25.87
40	49.41	17	0.55	39	26.14
20	51.74	29	0.58	21	26.89
21	53.78	46	0.58	42	28.17
36	58.03	5	0.64	37	28.86
42	84.53	12	0.67	36	29.02
41	98.46	2	0.69	41	32.82

VII. CONCLUSIONS

Project complexity plays a major crucial parameter in the project scheduling and the successfulness of the project with the targeted aim of its initiation and generation. Also, the project topography, features, and characteristics such as project activities, nodes, types of resource, their availability, ..etc have direct influence on project complexity. In the current research some new measures for project complexity indices have been proposed and test against the existing complexity measures. The proposed measures are in consistency with the variation trend of the existing measures. Also the proposed measures are more sensitive than the existing measures in the evaluation process of project complexity. However for the proposed measure, when (Ac) equals (A) then (W) equal to unity and the project will be serial structure in its activities and the proposed measure transformed into Badriu's measure. The main privilege of the proposed measure is that, it considers size, shape and logic characteristics, time characteristics, resource demands and availability characteristics as well as number of critical activities and critical paths or chains of the project.

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