Optimization of Computer-Based Assessment Session Scheduling at SMAN 1 Mandrehe Using the Graph Coloring Algorithm

Dermawan Hendrik Gulo, Zulham Sitorus

Abstract

Because there are fewer computers accessible than there are participants in computer-based examinations like the Academic Ability Test (TKA) and the National Computer-Based Assessment (ANBK), schools must split participants into many sessions. Session scheduling at SMAN 1 Mandrehe in West Nias Regency is now done by hand, which increases the possibility of conflicts between elective subjects, exceeds computer capability, and needlessly prolongs the assessment period. The goal of this research is to use a graph colouring technique to optimise computer-based assessment scheduling. Exam groups are represented as vertices, shared participants as edges, the quantity of participants as vertex weights, and sessions as colours in the conflict graph model of the problem. Weighted capacity limits are incorporated into the Welsh-Powell and DSatur algorithms to guarantee that each session is both conflict-free and does not surpass the number of operational computers. This quantitative applied study uses metrics like the number of sessions, distance to the lower bound, constraint violations, device utilisation, proctor workload distribution, and computational time to compare manual scheduling with capacity-constrained versions of the Welsh-Powell and DSatur algorithms. Using an illustrative dataset with twelve participants, six elective subjects, and eight computers, manual calculations reveal that typical graph colouring requires three sessions, one of which is impractical due to its nine participants. On the other hand, both capacity-constrained algorithms provide four viable and optimal sessions, improving computer utilisation from 50% to 75% and decreasing the overall number of sessions from six to four (a 33.3% increase in efficiency). These results show that graph colouring models need to incorporate device capacity restrictions. The suggested model is meant to be used as a tool for committee organization when creating evaluation schedules, especially in schools situated in resource-poor, undeveloped areas.

***Keywords**: Computer-Based BAsessment, DSatur, Graph Coloring, Exam Scheduling, Welsh-Powell*

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Introduction

In the last five years, the education evaluation system in Indonesia has been moving towards computer-based assessments. The government has replaced the National Examination with the Computer-Based National Assessment (ANBK), which evaluates the quality of educational units through surveys of literacy, numeracy, learning environment, and character surveys [1]. Regulation of the Minister of Primary and Secondary Education Number 9 of 2025 concerning the Academic Ability Test (TKA), which evaluates students' academic achievements in certain subjects, then expands this policy (Kemendikdasmen, 2025). The TKA for SMA/MA/SMK levels was first held in November 2025, with around 3.47 million students and a participation rate of 84.02% [2].

The two assessments are conducted at the implementing educational units and are fully computer-based. As a result, schools must have adequate information and communication technology infrastructure, which includes client computers, stable internet connections, local servers, and experienced technicians and proctors. The session mechanism allows students to take exams in shifts according to the number of available devices to assist schools with limited resources [3]. With this mechanism, the responsibility for scheduling sessions is given to the school level.

According to several studies, however, the readiness of facilities is the main obstacle in conducting computer-based assessments. [4] systematic review of twelve articles found that the most common issues are network and server disruptions, insufficient numbers of computers or laptops, device specifications that do not meet standards, and a lack of human resources. Due to limited devices and accompanying capabilities, schools in 3T areas are not yet fully prepared, [5]. Due to unstable networks and limited availability of laptops, SMAN 1 Danau Seluluk in Seruyan Regency had to implement ANBK semi-online, according to [6]. A similar condition was found by [7], who stated that the school had to divide the implementation into three sessions and borrow computers from other schools, and [8], who stated that the school only had five units of devices.

SMAN 1 Mandrehe is located in Nias Barat Regency, North Sumatra Province. This is an island region designated as an underdeveloped area by Presidential Regulation Number 63 of 2020. According to initial observations, the school has 25 client computer units, and the number of students participating in the assessment reaches 270 students. Thus, 11 sessions are required to be conducted. So far, the session schedule has been arranged manually by the committee. In previous implementations, issues occurred such as participants clashing with elective subjects, sessions exceeding room capacity, uneven proctor workload, or additional sessions due to network problems.

This scheduling problem is complicated. In the SMA level TKA, each student takes mandatory and elective tests with combinations that differ among students. Therefore, two test groups with the same participants should not be placed in the same session. On the other hand, the number of people who can participate in one session is limited by the number of operational computers, and each session requires a proctor and a technician. The exam scheduling class (exam time scheduling) is a problem with issues like this. This class is generally considered NP-complete, making it difficult to solve optimally by manual means.

Graph colouring, also known as graph colouring, is one of the most commonly used methods for modelling exam scheduling. In this model, each group of exams is represented as a node, each conflict that occurs between participants is represented as an edge, and each colour is represented as a session slot. The minimum number of colours, or the chromatic number, indicates the minimum number of uninterrupted sessions. Created a degree ordering algorithm for scheduling problems, [9] developed the DSatur algorithm that selects nodes based on saturation degree, and [10]created a colouring algorithm for large-scale scheduling problems. Malkawi et al. have implemented exam scheduling. [11], [12], who added increased space utilisation, and [13] who created the final semester exam schedule at Bina Nusantara University in eight slots.

School and course scheduling in Indonesia has utilised graph colouring. [14] used the Welsh-Powell algorithm to create a class schedule at SMAN 1 Kopang and obtained a chromatic number of 22. On the other hand, [15] used the Greedy and Welsh-Powell algorithms to create a class schedule at SMKN 16 Samarinda. Nevertheless, the focus of this research is on class schedules, semester exams, and weekly lessons. Meanwhile, research on ANBK and TKA in schools is usually descriptive qualitative in nature. This identifies obstacles without providing a solution model [4], [6], [7].

According to the conducted research, there has been no study that models the scheduling of computer-based assessment sessions at the school level as a graph colouring problem. This research considers conflicts in elective subjects, computer capacity per session, and the availability of proctors at the same time. This gap is very important because the quality of the session schedule directly affects the number of implementation days, the proctor's workload, and the risk of students being unable to participate in the assessment. This is especially true in schools like SMAN 1 Mandrehe, which have very limited facilities.

Therefore, this study proposes to optimise the scheduling of computer-based assessment sessions at SMAN 1 Mandrehe using a graph colouring algorithm. This study uses colouring algorithms (Welsh-Powell and DSatur) modified with computer capacity constraints to create conflict graphs from participant and test item data. Then, they compared the results of the manual schedule with the number of sessions, the number of conflicts, and the utilisation rate of the devices. The research results are expected to become a model that can be applied by other schools in 3T areas and serve as a tool for school committees and proctors.

Literature Review

2.1 Asesmen Berbasis Komputer di Sekolah

Computer-based assessments are a type of exam where questions, answers, and supervision are conducted through computer devices and networks. There are two main types of education in elementary and secondary schools. First, ANBK, which evaluates the quality of educational units and replaces the National Examination. Second, TKA, regulated by Permendikdasmen Number 9 of 2025, assesses students' academic achievements in certain subjects [16].

Both assessments were conducted in two different ways. Client computers are directly connected to the central server in online mode via the internet. The school uses a local server for the semi-online mode, which synchronises data with the central server before and after the exam. This method is ideal for schools with unstable networks [6]. Implementation requires technicians to manage the devices, as well as proctors to manage the server and sessions. Because the number of computers in many schools is smaller than the number of participants, the implementation is arranged in sessions, which is a period of time when a number of participants take the exam simultaneously. Each high school TKA student takes mandatory and elective tests according to their preferences. The variation in the combination of elective tests is what causes conflicts when scheduling the sessions.

2.2 Examination Timetabling

Scheduling is the allocation of a number of events into time slots and limited resources while meeting a number of conditions. One of its main components is exam scheduling, which includes placing each exam within a specific time frame so that participants do not have to take two exams simultaneously.

a. Hard constraints, which must be met for the schedule to be feasible. For example, no participant is scheduled for two exams in the same session, and the number of participants per session does not exceed the capacity.
b. Soft constraints, which should be met to improve the quality of the schedule. For example, the proctor's load is evenly distributed and the break between exams for a participant is quite long.

Table 1. Constraints in scheduling assessment sessions at SMAN 1 Mandrehe

\	**Type**	**Constraint**
H1	hard	Participants may not be scheduled for two groups of test subjects within the same session.
H2	hard	Number of participants per session ≤ number of working client computers
H3	hard	Each session has at least one proctor and one technician.
H4	hard	Number of sessions per day ≤ limit set by the organizer
S1	Soft	The workload for proctors and technicians is evenly distributed.
S2	Soft	There must be a gap of at least one session between any two exams taken by the same student.
S3	Soft	A make-up session is available for participants who were interrupted due to power or network issues.

2.3 Basic Concepts of Graphs

A graph G is defined as a pair of sets G = (V, E), where V is a non-empty set of vertices and E is a set of edges that connect pairs of vertices. Two vertices are said to be adjacent if they are connected by an edge. The degree of a vertex v, denoted as d(v), is the number of edges incident to v.

The graph can be represented by an n × n adjacency matrix A, with n = |V|:

$$a_{ij} = \begin{cases} 1, & \text{jika simpul } v_i \text{ dan } v_j \text{ bertetangga} \\ 0, & \text{jika tidak} \end{cases}$$

This representation is used by most graph-based scheduling research in Indonesia (Haniantara et al., 2023; Rahmah et al., 2026) because it is easy to build from tabular data.

2.4 Vertex Coloring and Chromatic Numbers

Vertex coloring is the assignment of a color to each vertex such that no two adjacent vertices share the same color. Formally, a k-coloring is a function c : V → {1, 2, …, k} that satisfies c(u) ≠ c(v) for every edge (u, v) ∈ E. The chromatic number χ(G) is the smallest value of k for which G admits a k-coloring.

Determining χ(G) exactly is NP-hard (Garey & Johnson, 1979), but its bounds can be easily calculated. Welsh and Powell (1967) established an upper bound that serves as the basis for their algorithm:

$$\chi(G) \leq \max_{1 \leq i \leq n} \min\{d(v_i) + 1,\ i\}$$

With the vertices ordered such that $d(v_1) \geq d(v_2) \geq \ldots \geq d(v_n)$. Meanwhile, the size of the largest clique, ω(G), provides a lower bound: χ(G) ≥ ω(G). If the result from the heuristic equals ω(G), then the obtained schedule is proven to be optimal.

2.6 Conflict Graph for Exam Scheduling

A valid coloring ensures that constraint H1 (no participant clashes) is met. However, classical coloring does not guarantee constraint H2 (computer capacity), as the total number of participants in groups assigned the same color could potentially exceed the number of available computers.

Exam scheduling is modeled as a conflict graph. In this study, the model is mapped as follows:

Table 2. Graphic element and Significance in session scheduling

Graphic element	**Significance in session scheduling**
V-knot	One exam group, namely a group of students who take the same test item
Edge (u, v)	Groups u and v share at least one student, so they cannot be in the same session.
Weight w(v)	The number of participants in group v, which determines computer usage
Color c(v)	Session number for which group V is scheduled
χ(G)	Minimum number of conflict-free sessions

Research Methodology

This study is applied research that uses computational experiments on a single case study. Applied research was chosen because its goal is not to test a theory; rather, its goal is to solve a real problem, namely creating a schedule for assessment sessions in educational institutions. Because the performance of the algorithm is measured with comparable numerical metrics, a quantitative approach is used.

The construction of the experiment compares three treatments with the same information:

Table 3. Experiment Compares

Code	Treatment	Information
P0	Manual schedule	The session schedule prepared by the school committee for the previous implementation (control)
P1	Welsh-Powell has a capacity of	Welsh-Powell algorithm (Welsh & Powell, 1967) with a check of computer capacity
P2	Capacitated DSatur	The DSatur algorithm (Brélaz, 1979) with a check of computer capacity

The research process is carried out in six sequential stages, with a schedule feasibility decision point where the process returns to the preprocessing stage if hard constraints have not been met. Figure 1. shows the flow and the outputs of each stage.

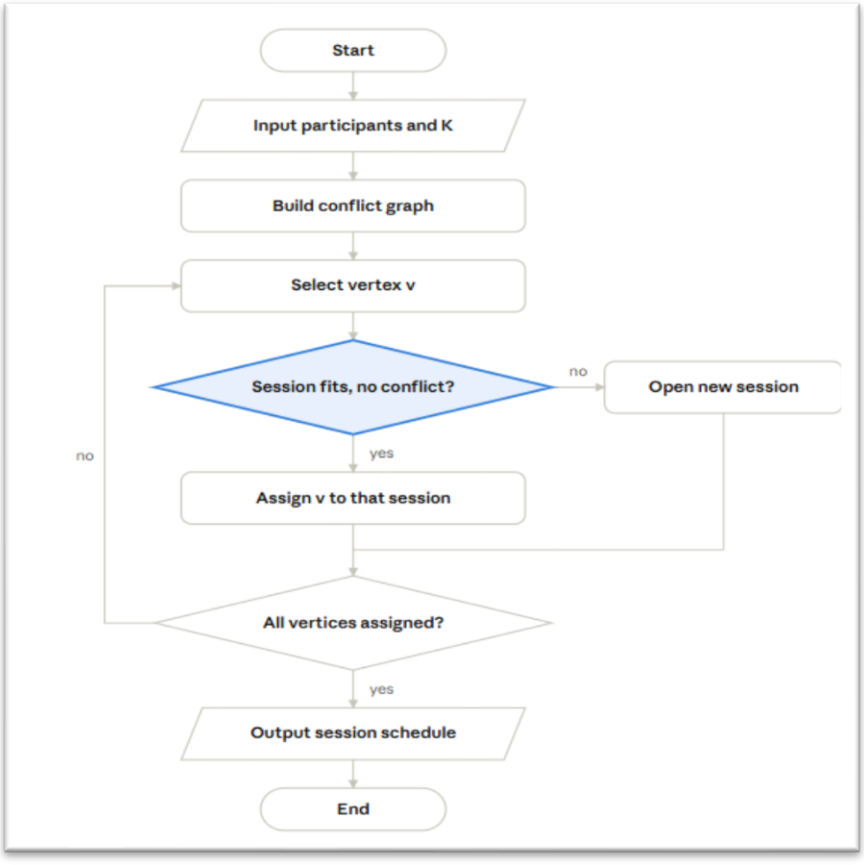


Figure 1. Research Framework

The fundamental change in this study is the first decision point (shown by colour): a node is only allocated to a session that is conflict-free and still has computing capacity left; if no such session exists, a new one is established. This procedure is repeated at the second decision point until every examination group has been allocated to a session, with the total number of colours, k, representing the number of sessions produced.

Results

4.1 Data and Calculation Analysis

The following information was utilised in the computation:

a. Twelve high school students (P01–P12) took the TKA (Academic Competency Test) in this example.
b. Out of the six elective courses offered, each student chooses two: Physics (FIS), Chemistry (KIM), Biology (BIO), Economics (EKO), Geography (GEO), and Sociology (SOS).
c. Functional client computer capacity: K = 8 units each session.
d. The graph-based approach concentrates on elective subjects, which are the main cause of scheduling problems; mandatory topics must be taken by every student and are therefore scheduled separately.
e. One technician and two proctors (Proctor A and B) are available; the daily cap is set at two sessions (constraint H4).

Table 1. Participant Data and Test Subject Selections

Participant Code	Test Subject 1	Test Subject Option 2
P01	Physics (PHYS)	Chemistry (KIM)
P02	Physics (PHYS)	Biology (BIO)
P03	Chemistry (KIM)	Biology (BIO)
P04	Physics (PHYS)	Chemistry (KIM)
P05	Economics (EKO)	Geography (GEO)
P06	Economics (EKO)	Sociology (SOC)
P07	Geography (GEO)	Sociology (SOC)
P08	Economics (EKO)	Geography (GEO)
P09	Biologi (BIO)	Geography (GEO)
P10	Chemistry (KIM)	Economics (EKO)
P11	Physics (PHYS)	Biology (BIO)
P12	Sociology (SOC)	Geography (GEO)

4.2 Formation of Examination Groups and Weighting

A single examination group is made up of each elective test subject (node v). The weight w(v), which is determined by adding the test subject's occurrences in Table 1, represents the number of individuals taking that test subject.

Table 2. Examination Groups and Weights w(v)

Knot (v)	Test Subject	Participant	w(v)	w(v) ≤ K = 8?
v1	PHYS	P01, P02, P04, P11	4	Ya
v2	KIM	P01, P03, P04, P10	4	Ya
v3	BIO	P02, P03, P09, P11	4	Ya
v4	EKO	P05, P06, P08, P10	4	Ya
v5	GEO	P05, P07, P08, P09, P12	5	Ya
v6	SOS	P06, P07, P12	3	Ya
	Value		24	

Twelve participants × two elective test subjects are represented by the total weight $\Sigma w(v) = 4 + 4 + 4 + 4 + 5 + 3 = 24$. No groups need to be divided because all $w(v) \leq 8$.

4.3 Handling of Mandatory Test Items

Since all 12 participants must take the required test, $w = 12 > K = 8. This group is separated according to the preprocessing procedures that will be covered later: subgroups \lceil w(v) / K \rceil = \lceil 12 / 8 \rceil = \lceil 1.5 \rceil = 2. Every mandatory test subject, such as subgroup 1 with six participants and subgroup 2 with six participants, must be scheduled over two sessions. The discussion that follows concentrates on elective exam subjects, for which participant combinations differ, since mandatory test subjects follow a set pattern for all schools.

4.4 Construction of a Conflict Graph

If groups u and v have at least one participant in common, an edge (u, v) is created. Each participant creates one conflict pair since they choose exactly two test subjects.

Table 3. List of edges in the conflict graph

No	Side (u, v)	The same participant	Number of participants
1	(PHYS, KIM)	P01, P04	2
2	(PHYS, BIO)	P02, P11	2
3	(KIM, BIO)	P03	1
4	(EKO, GEO)	P05, P08	2
5	(EKO, SOS)	P06	1
6	(GEO, SOS)	P07, P12	2
7	(BIO, GEO)	P09	1
8	(KIM, EKO)	P10	1

4.5 Adjacency Matrix and Vertex Degree

If vertices I and J are nearby, the value a_{ij} = 1; otherwise, it is 0. The total of the entries in a row of the matrix is the degree d(v).

Table 4. Adjacency matrix A and vertex degrees

	PHYS	KIM	BIO	EKO	GEO	SOS	d(v)
PHYS	0	1	1	0	0	0	2
KIM	1	0	1	1	0	0	3
BIO	1	1	0	0	1	0	3
EKO	0	1	0	0	1	1	3
GEO	0	0	1	1	0	1	3
SOS	0	0	0	1	1	0	2

The sum of all degrees, $\Sigma d(v) = 2 + 3 + 3 + 3 + 3 + 2 = 16 = 2|E|$, is consistent with the handshaking lemma; therefore, the matrix has been constructed correctly.

4.6 Capacitated DSatur (P2)

At each iteration, the uncolored node with the largest degree of saturation sat(v), namely the number of different sessions that its neighbors have used, is selected. If it is a tie, the largest degree is chosen, then the largest weight, then the alphabet. Nodes are assigned the smallest numbered sessions that are conflict-free and still fit; if not, a new session is opened.

Table 7. Iterations of capacitated DSatur (K = 8)

Iteration	sat(v) uncolored node	Selected (reason)	Session check	Session
1	all = 0	GEO (d = 3, w = 5 at its largest)	no session yet → open session 1	1
2	BIO=1, EKO=1, SOS=1, PHYS =0, KIM=0	BIO (series with EKO; alphabetical)	S1: GEO conflict → open session 2	2
3	PHYS =1, KIM=1, EKO=1, SOS=1	EKO (d = 3; KIM series; alphabetical)	S1: GEO conflict; S2: 4 + 4 = 8 ≤ 8	2
4	PHYS =1, KIM=1, SOS=2	SOS (greatest saturation)	S1: GEO conflict; S2: ECO conflict → open session 3	3
5	PHYS =1, KIM=1	KIM (d = 3 > d(FIS) = 2)	S1: 5 + 4 = 9 > 8; S2: conflict; S3: 3 + 4 = 7 ≤ 8	3
6	PHYS =2	PHYS (the only one)	S1: 5 + 4 = 9 > 8; S2, S3: conflict → open session 4	4

P2 Results: with k = 4 sessions, Session 1 = {GEO}, Session 2 = {BIO, EKO}, Session 3 = {SOS, KIM}, and Session 4 = { PHYS }. The sequence in which the nodes are processed is the only distinction between these results and P1's. It makes sense for both methods to produce the same schedule for small, balanced datasets like this one; performance differences are anticipated when applied to bigger school datasets.

4.7 Evaluation and Comparison

For comparison, the manual schedule (P0) is illustrated using the method commonly employed by the organizing committee—assigning one elective test subject per session—which necessitates a total of 6 sessions.

$$\text{Utilization} = \Sigma w(v) / (k \times K) \times 100\%$$

$$\text{Efficiency} = (k_manual - k_algorithm) / k_manual \times 100\%$$

Utilization calculation:

a. P0: 24 / (6 × 8) × 100% = 24 / 48 × 100% = 50.0%
b. P1 and P2: 24 / (4 × 8) × 100% = 24 / 32 × 100% = 75.0%
c. Classic Welsh-Powell: 24 / (3 × 8) × 100% = 100% by computation; however, because Session 1 had nine participants, the schedule is not viable.

The efficiency of P1 and P2 in relation to P0 is calculated:

Efficiency = (6 − 4) / 6 × 100% = 2 / 6 × 100% = 33.3%

Proctor workload: Proctors A and B are each assigned 2 sessions, resulting in a standard deviation of 0 (evenly distributed).

Table 8. Recapitulation of manual calculation results

Metriks	P0 Manual	WP Klasic	P1 WP Capacity	P2 DSatur Capacity
Number of sessions (k)	6	3	4	4
Distance to LB (k − 3)	3	0	1	1
H1 Violation (clash)	0	0	0	0
H2 violation (capacity)	0	1 sesi	0	0
Suitable for use?	Yes	No	Yes	Yes
Device utilization	50,0%	–	75,0%	75,0%
Efficiency relative to P0	–	–	33,3%	33,3%
SD proctor workload	0	–	0	0

Metriks	P0 Manual	WP Klasic	P1 WP Capacity	P2 DSatur Capacity
Status optimal	No	–	Optimal (k = 4)	Optimal (k = 4)

Conclusion

Because there are fewer computers accessible than there are participants in computer-based examinations like the TKA (Academic Competency Test) and ANBK (National Assessment-Based Computer Test), schools must split participants into several sessions. Session scheduling has historically been done by hand at SMAN 1 Mandrehe, which is situated in an undeveloped area with few facilities. There are dangers associated with this strategy, such as participant schedule issues, sessions that exceed computer capacity, and an ineffective number of testing days. According to published research, this topic can be represented as a graph colouring problem with examination groups acting as vertices, participant disputes acting as edges, and sessions acting as colours. Nevertheless, computer capacity limitations have not yet been incorporated into such models in Indonesian research. As a result, this study suggests using the Welsh-Powell and DSatur algorithms—modified to incorporate a weighted capacity check—and contrasts them with the manual scheduling procedure used by the school.

The suggested improvement is both essential and effective, as shown by manual calculations based on illustrative data. Three conflict-free sessions are produced via classic graph colouring, but one of these sessions needs nine participants for just eight computers, making the schedule impractical. On the other hand, four workable and clearly ideal sessions are produced by the Welsh-Powell and DSatur algorithms. In comparison to the manual timetable, this raises computer utilisation from 50% to 75% and decreases the total number of sessions from 6 to 4 (a 33.3% improvement in efficiency). These findings are merely illustrative; after the model is applied to the school's real participant data and accessible computer inventory, the optimal procedure for SMAN 1 Mandrehe will be decided.

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