Joint Seat Allocation 2018: An algorithmic perspective

Technical Report

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Abstract

Until 2014, admissions to the Indian Institutes of Technology (IITs) were conducted under one umbrella, whereas the admissions to the non-IIT Centrally Funded Government Institutes (CFTIs) were conducted under a different umbrella, the Central Seat Allocation Board (CSAB). The same set of candidates were eligible to apply for a seat in each of the two sets, and several hundred candidates would indeed receive two seats from the two different sets. Each such candidate could use at most one of the seats, leaving a vacancy in the other seat; this would be noticed much later, in many cases after classes began. Such seats would either remain vacant or would be reallocated at a later stage, leading to logistical hardship for candidates, or inefficiency in seat allocation in the form of unnecessary vacancies, and also misallocation of seats (e.g., a particular CSAB seat could be offered to a candidate A, despite denying the same seat earlier to a candidate B with better rank, who had meanwhile taken some IIT seat). The two sets also operated under different time windows, with the net result that classes would begin later in the academic year, compared to, say, colleges offering only the sciences.

Since 2015, a new joint seat allocation process has been implemented improving the efficiency and productivity of concerned stakeholders. The process brings all CFTIs under one umbrella for admissions: 100 institutes and approximately 39000 seats in 2018. In this scheme, each candidate submits a single choice list over all available programs, and receives no more than a single seat from the system, based on the choices and the ranks in the relevant merit lists. Significantly, overbooking of seats is forbidden.

Earlier [3], we described the Multi-Round Multi-Run Deferred Acceptance scheme that was first used for the joint seat allocation in 2015. Crucially, unlike the 2014 and earlier admissions processes, the scheme seamlessly handles multiplicity of merit lists across different institutes and programs; indeed every program may have a separate merit list, and these lists need not have any relation with each other. In addition, the scheme has several other desired objectives. The scheme makes it safe and optimal for candidates to report their true preferences over programs. The seat allocation produced does not waste seats and is fair in the sense that it does not give a seat to a lower-ranked candidate when it was denied to a higher ranked candidate. Further, the allocation is optimal in a formal sense, providing each candidate with the best possible seat subject to fairness. Without compromising on these tenets, the scheme factors in various business rules, including reservations for different birth categories, reservations for home state candidates, and rules regarding dereservation when sufficient candidates are not available. The scheme also factors in changes that are inevitable when it is discovered, for instance, that candidates have inadvertently or otherwise, incorrectly declared their birth category, or when it is discovered that the qualifying criteria have been incorrectly recorded by state education authorities.

Over a period of the last four years, several business rules have changed, added, or dropped. Principal among them is a rule requiring the allocation of supernumerary seats to females, provided the program did not have a sufficient desired percentage, while, at the same time, not reducing the amount of seats available to non-females. The current report incorporates all old and new business rules that were used in 2018, thereby displaying the versatility of the original method. Instead of providing only changes, this report provides more details of other process improvements made since 2015, and up to 2018. We hope that this self contained report will be helpful for the reader, and will also serve as a valuable reference for joint seat allocations in future years as well.

Looking forward, we posit first that it is inevitable that different colleges will prefer different mechanisms of judging merit, and assigning relative rank. For example, programs such as Architecture and those in the Humanities require different skills. The IITs do not use higher secondary marks in their admission process. States may impose home quotas, and the Government of India recognizes quotas (and preferential allotment) among certain birth categories. We believe the ability of our algorithm to gracefully handle multiple merit lists gives us hope to express optimism that all undergraduate admissions in the country, beyond the CFTIs, can beneficially use the suggested scheme.
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Chapter 1

Introduction

Allocation (earlier, counseling) of students to seats in colleges is a key step in the admission process from an institutional perspective. It decides the final fruit of all the hardships taken by a candidate over years of schooling and special preparations for competitive examinations. Importantly, this decision shapes the candidate’s future career. For better or for worse, currently in the Indian system, seats are allocated based on marks obtained in competitive exams such as the Joint Entrance Examination (JEE). A lot of care needs to be taken to ensure that the appropriate seat is delivered to the candidate.

Until 2014, two different entrance examination-based methods were available for a candidate to obtain a seat in undergraduate engineering disciplines offered by the Centrally Funded Technical Institutions (CFTI) including the Indian Institute of Technologies (IITs). The admissions to the IITs were conducted under one umbrella, whereas the admissions to the non-IIT (CFTIs) were conducted under a different umbrella, the Central Seat Allocation Board (CSAB). This system resulted in an inefficient allocation.

Example 1. Consider an applicant Rohini who was assigned B.Sc. Chemistry in IIT Bombay through her rank in the IIT JEE (Advanced) exam. She is unable to obtain her dream choice of a B.Tech. program in Chemical Engineering at the National Institute of Technology (NIT), Nagpur in the first round of counseling administered by CSAB (due to her relatively poorer rank in her JEE Mains exam). While Rohini was offered Civil Engineering in NIT Silchar, she rejected this offer from CSAB, and settled for the B.Sc. program at IIT Bombay.

For another candidate Bhavesh, it is the opposite. He is successful in getting B.Tech., Chemical Engg. at VNIT but, having a lower rank than Rohini in the JEE (Advanced), does not get a seat in IIT Bombay. He decides to stay back in his home state of Gujarat and rejects the VNIT seat and also elbows out a local candidate, Gurjar, in L.D. Engg. College, Ahmedabad.

In the subsequent rounds of CSAB allocation, Rohini is annoyed to find a candidate (with marks lower than her own) allotted her favored Chemical Engg. seat at VNIT. Rohini realizes that if she had accepted the Civil Engineering seat at NIT Silchar she would have obtained a seat in VNIT in the final reckoning. In this process, she would have left a seat vacant in IIT Bombay.

Meanwhile, recent high school graduate Gurjar, and most likely his parents, were trying to get a train ticket to Assam in the hope of securing a civil engineering seat in Silchar in the so-called spot round.
Taking a step back, we observe that two different points of view need to be considered to correctly allocate seats — the point of view of the candidates, and the point of view of the participating institutions. All candidates should get the best available choice, and every institution should fill all seats in the varying courses they offer. Consistent efforts have been taken by different organizations in charge of counseling to satisfy both viewpoints.

Many institutions have grown to a stature of national importance. Each of them have their own entrance examination for admission and also have a separate rank list and a separate allocation process. Previously, the candidate filled a choice sheet for each of these institutions, or sometimes, group of institutions. Thus, there was no provision in the past for the candidate to list her choices in a single choice sheet across all institutions. Every choice sheet he filled could indicate only the preferences of the candidate among available choices in the institution he applies to. As a result, the candidate who filled $K$ choice sheets may receive admission to up to $K$ programs from which he has to select one. However, as counseling dates are not synchronized, and there is no legal provision for overbooking seats, the candidate may rationally block more than one seat by paying required fees for safety reasons. At most one of these seats is occupied by the candidate, whereas the remaining seats go vacant. As different allocation processes have no mechanism to track this, many seats in unpopular (in the eyes of the young candidates) courses end up being unfilled. At the same time, many candidates in the waiting lists could not be admitted as the decision of the deserting candidates who have been allotted a course is known only after the courses start and that becomes too late.

For better or for worse, overbooking of seats is not allowed by the authorities.

Different institutions and admission boards have tried different mechanisms to alleviate this problem, which in our opinion are not very effective, leading to allocation inefficiency as well as logistical difficulties for candidates and institutes. Some of these mechanisms are:

1. **Spot admissions after classes begin:** Many institutions do this admission within a very short window of time. It becomes practically impossible for the candidates to move around thousands of kilometers attending one spot round after another. Not only there are severe logistical costs, there is also inappropriate allocation of seats.

2. **Penalty:** When a candidate blocks a seat in a course the amount he pays may not be refunded if he does not accept the admission offer; further the candidate may not be allowed to write the entrance examination for the corresponding institution the next year. Such penalties may be infeasible or may not be effective.

**Solution**

So what is the solution? Rather than passing the buck to the candidate, one can ask “Why don’t the different admission bodies join together and solve the problem?” With this view this document describes the details of a Joint Seat Allocation process. It has been successfully implemented since 2015. The participating institutes are IITs, NITs, and Other-GFTIs (Government funded technical institutes.)

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1. In fact, in 2014 candidates holding a CSAB seat were not permitted to participate in the CSAB spot round causing so-called rank violations.
2. The courts have typically insisted on a full refund of fees.
The process which we formulated conducts a single window multi-round counseling for admissions to the Centrally Funded Technical Institutions (CFTI) based on the JEE (Main) and JEE (Advanced) examination. Note that there are multiple sets of merit lists. We note that each set comprises merit lists for the General (GEN) category, Other Backward Castes Non-Creamy Layer (OBC-NCL) category, Scheduled Caste (SC) category, Scheduled Tribe (ST) category, and Persons With Disability (PwD) category. The candidate fills only one choice list indicating her choices from programs offered across all CFTIs. Thus, the admission bodies get a global view of the choices and, in principle and practice, a better allocation is possible that incorporates both the candidate viewpoint and the institutional viewpoint.

We believe that the problem of a single window Joint Seat Allocation is non-trivial. In the current context, we require a careful adaptation of existing methods based on the celebrated Deferred Acceptance algorithm by Gale and Shapley. Our scheme is truthful, namely the scheme makes it safe/optimal for each candidate to report her true preferences over programs in her submitted choice list. The seat allocation produced does not waste seats and is fair/stable in the sense that it does not give a seat to a lower ranked candidate that was denied to a higher ranked candidate. Further, the allocation is optimal in a formal sense, providing each candidate with the best possible seat subject to fairness. See Section 2.2 for formal definitions.

With the implementation of this scheme in the last 4 years, the joint seat allocation has led to a substantial reduction in vacancies in the IITs quantified in [4]. The reduction in vacancies in CSAB institutes have been more modest. We discuss methods to minimize these vacancies in [4].

1.1 Organization of the report

Chapter 2 presents the problem formally along with introducing some basic notations and terminologies to be used in the rest of the report. Chapter 3 first presents the deferred acceptance (DA) algorithm in its simplest form. Later it describes the version that handles two important aspects of multiple rounds, namely, Min-Cutoff and multiple candidates with the same rank. Chapter 4 describes some fundamental business rules for admissions into three types of institutes, and how they are incorporated using virtual programs and virtual preference tables. Chapter 5 presents the complete description of the multiple round DA algorithm. Chapter 6 presents the way de-reservation is handled in each round by executing multiple runs of our algorithm. In view of this consideration, we term our scheme as MRDA, a multi-run deferred acceptance scheme. Chapter 7 presents the adaptation of the rule of supernumerary seats for females. In Chapter 8 and Chapter 9, we conclude with a brief summary of the impact of joint seat allocation in the last 4 years along with the recommendations for future years.

Finally, in Chapter 10, which is the Appendix, we provide the details of the following aspects of the MRDA algorithm and Joint Seat Allocation 2018:

1. A key requirement, that of increasing the ratio of females to males, cropped up in 2018. While Chapter 7 introduces the constraints, and provides our algorithm, first look alter-
native algorithms that have significant drawbacks are listed in the appendix for a better understanding of the nuances.

2. A summary of the activities at the reporting center during a round that influences the seat allocation of the next round.

3. Survey questions that are asked when a candidate refuses a seat

4. Validation modules required to ensure that the seat allocation produced meets all business rules.

5. Implementation details of MRDA.

6. The changes in the business rules of the joint seat allocation since 2015.

7. Implementation details of a 2015 business rule that we believe may be interesting to practitioners elsewhere.

8. History and background of the admission process to engineering colleges in India.

9. The challenge and opportunity of overbooking seats to reduce vacancies
Chapter 2

Preliminaries

2.1 Background and Challenges

In the case of a single merit list, candidates are sequentially ordered, and the allotment of seats is done by processing candidates in the same order and allowing each candidate to choose from among the seats that are still available. For example, consider three candidates, A, B and C. If in the NIT merit list, they are ranked as A, B and C, then, given the choices of A, B and C for different branches, we give preference to A over B and C. Likewise, we give preference to B over C. The allotment process first allocates a seat to A, then to B, and finally to C.

In practice, the process is much more intricate as one has to take care of various categories like GEN, OBC-NCL, SC, ST, PwD, their cut-offs, and then recouping of unallocated OBC-NCL and PwD seats. Nevertheless, a solution can, and has been devised.

Unfortunately, if we have multiple merit lists, the issues are much more complex. Consider a simple scenario of three merit lists, namely those of the IITs, the NITs and a merit list for the Architecture (ARCH) program in which an additional examination needs to be cleared. Again consider our 3 candidates, A, B and C. Let the three merit lists be as follows:

NIT merit List: (1, A), (2, B) and (3, C) (as mentioned earlier)

IIT Merit List: (1, B), (2, C), and (3, A)

ARCH merit List: (1, C), (2, A) and (3, B)

Note that now, unlike in the case of a single merit list, there is no overall strict ordering among A, B and C as their relative performance is different in the three examinations. In practice, we may have several merit lists covering tens of examinations and lakhs of candidates.

Now consider a joint seat allocation process where each candidate fills up a single choice sheet. An example is shown below where we assume, for illustration, that there is only a single seat available in each program.

A: 1: IIT, 2: ARCH, 3: NIT

\[1\] This is known as serial dictatorship in the literature [10].
Note that the choices of the candidates are their personal preferences and may not have any linkages to their relative ranks in different merit lists.

How do we allocate seats? The first condition that comes to one’s mind is fairness. Fairness may appear straightforward: A candidate’s choice for a program should be honored in the order of merit for that program. In the example, since candidate B does express a preference to go to NIT, it should never be the case that any candidate in the NIT merit list worse than B displaces B, and denies B a seat; B may however be given a seat which she prefers to NIT, say ARCH.

Given multiple merit lists, there may be several solutions for the same choices that satisfy fairness. Consider three different allocations:

Allocation 1: A (NIT), B (IIT), C (ARCH)
Allocation 2: A (ARCH), B (NIT), C (IIT)
Allocation 3: A (IIT), B (ARCH), C (NIT)

Allocation 1 is fair because A is ranked first in NIT merit list, B is ranked first in IIT merit list and C is ranked first in ARCH merit list. But Allocation 1 gives each candidate their worst choice. In fact, should A and B meet each other, they would be willing to swap their allocation! Allocation 2 is also fair, and better from the candidate’s point of view than Allocation 1 because it gives everyone their second choice. Finally, Allocation 3 is also fair, and better than both Allocations 1 and 2 from the candidate’s point of view because everyone gets their first choice. This brings about the following scientific question, given that fairness is not good enough.

Is there a “best” choice among the different available fair allocations, and how can one compute it?

We have highlighted these questions through a simple scenario. The solution gets complicated when we have the practical situations of lakhs of candidates having to fill a common choice list over multiple merit lists where each institution have their own business rules in the handling of state and central SC/ST/OBC-NCL/PwD categories, multi-session allocation, and spot allocations².

This document presents details of design, analysis and implementation of a scalable solution to the problem mentioned above.

²In the simple case with no categories, § shows that there is a unique candidate optimal fair allocation, which simultaneously gives each candidate their best possible fair allocation. Further, this allocation can be computed using the candidate-proposing deferred acceptance algorithm.
2.2 Formal Problem Statement

We start with a simplified problem with multiple merit lists for the different programs. Differing programs may have the same merit list, or may have different merit lists. As discussed earlier, the problem is complex, but we term it ‘simplified’ for now because (for example) there are no quotas or ties in the presentation of this section.

Let \( P \) be the set of programs. For a program \( p \in P \), let \( c(p) \) denote the number of seats in \( p \). Let \( A \) denote the set of applicants (or candidates), with \( |A| = A \) being the number of candidates. Each candidate is allowed only one seat in the system. Candidates are asked to submit a choice (or preference) list over programs; the choice list is a strictly ordered list containing any subset of the programs in \( P \).

We denote the preference list of candidate \( x \) by
\[
\text{Pref}(x) = p_{x,1}, p_{x,2}, \ldots, p_{x,n(x)}
\]
which means that candidate \( x \) has listed \( n(x) \) programs, with program \( p_{x,1} \) being her top choice, program \( p_{x,2} \) being her next choice and so on. The candidate is asked to list only programs she is interested in.

Each program must submit its capacity \( c(p) \), as well as its merit list of candidates, which is a strictly ordered list containing a subset of the candidates in \( A \). We denote the merit list of program \( p \) by
\[
\text{Merit}(p) = x_{p,1}, x_{p,2}, \ldots, x_{p,m(p)}
\]
which means that program \( p \) has ranked \( m(p) \) candidates in its merit list, with candidate \( x_{p,1} \) ranked 1, candidate \( x_{p,2} \) being ranked 2, and so on.

Let \( \mu(x) \in P \) be the program allotted to candidate \( x \) by some mechanism, with some candidates possibly not getting any seat, in which case we write \( \mu(x) = \phi \). Denote the overall allocation by \( \bar{\mu} = (\mu(x))_{x \in A} \). We want a mechanism with the following properties:

1. Fairness: Suppose candidate \( x \) is allotted program \( p \). Then for any other candidate \( y \) such that \( y \) has a better (smaller) rank than candidate \( x \) in the merit list of \( p \), the allocation of \( y \) should be \( p \) or some other program that \( y \) prefers to \( p \).

Further, the mechanism must ensure that a candidate is not allotted a program that she did not list, and that no program is allotted to a candidate that was not a part of the merit list of the program.

2. Optimality: There does not exist any other allocation \( \mu' \) that satisfies the Fairness property, and provides any candidate \( x \) with an allocation she prefers to \( \mu(x) \) based on her preference list.

3. Truthfulness: The mechanism must make it optimal for candidates to report their true preferences.

A priori it is unclear that a mechanism satisfying all these properties exists. However, it turns out that such a mechanism does exist, and was constructed by Gale and Shapley. \cite{7}.

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\footnote{One may view the word ‘program’, ‘course’, ‘branch’ and ‘programme’ interchangeably in the rest of the document. For ease of understanding at this stage, one may think of a program as a college having a single course, say, Electrical Engineering in IIT Kharagpur.}

\footnote{This property is called stability in the literature \cite{7}.}

\footnote{This property is called individual rationality in the literature \cite{10}.}
2.3 Previous Work

An initial solution to the simplified problem was proposed by Gale and Shapley in 1962 [7] by formulating it as a “Stable marriage problem”. The proposed solution was shown to have a multitude of desirable properties including fairness and candidate optimality [7], and truthfulness [6] (no candidate or group of candidates can benefit from misreporting their preferences). The Gale and Shapley mechanism has been adapted and implemented successfully in a multitude of real world settings, e.g., the National Residency Matching Program (NRMP) (running in the USA since 1951, redesigned in 1999 [9]), New York City high school admissions since 2003 [1], and school and college admissions in Hungary [5].

However, our problem involves a variety of business rules governing flows of different systems that need to be streamlined for evolving a sound process of common allocation. We need to suitably adapt the Gale-Shapley mechanism to incorporate these business rules while retaining all these desirable properties. In the sequel, we demonstrate these and come up with a practical algorithm.
Chapter 3

A Combined Seat Allocation Scheme

Our proposed mechanism first collects information from the participating programs and candidates. It then uses this information to produce an allocation of seats.

3.1 Initial Information collection

Each participating program provides two pieces of information:

- The capacity \( c(p) \), i.e., the number of available seats
- A merit list of eligible candidates (Equation 2.2). The purpose of a merit list of program is to compare two candidates. For implementation of the algorithm, it is quite possible that this merit list is not explicitly computed. Instead, the relative order of any two candidates can be determined from the information associated with each of them (marks, birth category, PwD status).

Each candidate (who is eligible for at least one program) enters a preference list (Equation 2.1) of programs for which she is eligible, with the first entry being her most preferred program, the next entry being her next most preferred program, and so on.

We now describe the algorithm for allocating programs to candidates which incorporates all the business rules (see Chapter 4), and has three properties, namely, fairness, candidate-optimality, and truthfulness.

The Deferred Acceptance (DA) algorithm that forms the core of the joint allocation is described in the following section.

3.2 Basic DA algorithm

We stress that in the DA algorithm, “applications”, insertions into “waitlists” and “rejections” mentioned are all merely part of the algorithm, and do not actually involve any participation from the candidates and programs in the real world. That is, the algorithm internally generates applications, using the information that the candidates and programs have provided. We now state the algorithm in words. See Section 3.3 for the complete pseudocodes.

Input:
• For each program, its capacity and the rank list of eligible candidates.
• For each candidate, a preference list of programs.

Algorithm:

1. All candidates apply (in any order) to the first program in their preference list.

2. Each program \( p \) considers the applications it has received. Applications from candidates who are not eligible are immediately dropped. Let the capacity of the program be \( c(p) > 0 \). If the program has received \( c(p) \) or fewer eligible applications, then it retains all candidates on a waitlist. Otherwise, it ranks the candidates making these requests (as per the merit list of the program) and retains only the \( c(p) \) best candidates on its waitlist, and rejects other candidates.

   If no rejections are made by any program, the algorithm terminates.

3. Only rejected candidates apply (in any order) to the next program on their list, if any, and the algorithm returns to Step 2.

   If not even a single application is generated, then the algorithm terminates.

Output: When the algorithm terminates, the (final) “wait list” for each program \( p \) constitutes candidates admitted to program \( p \).

We present complete details of the DA algorithm through pseudocode in the following sections.

3.3 Pseudocode

Denote rank of candidate \( x \) with respect to \( \text{MERIT}(p) \) by \( \text{RANK}(x, p) \). For a list \( l \), denote the number of entries in the list by \( \text{LENGTH}(l) \).

We narrate two versions of the pseudocode. In the first version, the assumption is that the entire seat allocation happens in a single round and all candidates in a merit list have distinct ranks. It is presented to understand the general flow of the algorithm. The second version gets rid of this assumption, and is for multi-round scenarios as described in Chapter 5. In particular, it handles two non-trivial issues (i) there may be multiple candidates with the same rank, (ii) the credentials of candidates, and thus relative ordering, may change between rounds.
Algorithm 1 Deferred Acceptance Simple Version

INPUT:
Candidates $A$, Programs $P$
Preference list $PREF(x)$ for each $x \in A$
Capacity $c(p)$ and merit list $MERIT(p)$ for each $p \in P$

OUTPUT:
For each candidate $x \in A$, the allocation $\mu(x) \in P \cup \{\emptyset\}$
Also for each program $p \in P$, the list of admitted candidates $WAITLIST(p)$

1: for all $p \in P$ do
2: Create an empty ordered list $WAITLIST(p)$ that will consist of candidates ordered by their rank in $MERIT(p)$
3: end for
4: Create an empty queue $Q$
5: for all $x \in A$ do
6: $i(x) \leftarrow 1$ \hspace{1cm} \text{$\triangleright$ Initialize list position to 1.}
7: if $\text{LENGTH}(PREF(x)) > 0$ then
8: $\text{ENQUEUE}(x, Q)$ \hspace{1cm} \text{$\triangleright$ $x$ enters queue $Q$}
9: end if
10: end for
11: while $Q$ is non-empty do
12: $x \leftarrow \text{DEQUEUE}(Q)$ \hspace{1cm} \text{$\triangleright$ $x$ is any candidate removed from queue $Q$}
13: $p \leftarrow p_{x,i(x)}$ \hspace{1cm} \text{$\triangleright$ $x$ applies to program $p_{x,i(x)}$}
14: if $x$ is not eligible for $p$ then
15: $\text{REJECT}(x)$
16: continue
17: end if
18: end while
19: if LENGTH(WaitList(p)) = c(p) then ▷ The waitlist is full
20: y ← Last candidate in WaitList(p)
21: if RANK(x, p) < RANK(y, p) then
22: Remove y from WaitList(p)
23: REJECT(y)
24: Insert x into ordered list WaitList(p) at correct location
25: else
26: REJECT(x)
27: end if
28: else
29: Insert x into ordered list WaitList(p) at correct location
30: end if
31: end while
32: for all x ∈ A do
33: if p_{x,i(x)} exists in Pref(x) then
34: µ(x) ← p_{x,i(x)}
35: else
36: µ(x) ← ∅
37: end if
38: end for
39: return µ(x) for all x ∈ A and WaitList(p) for all p ∈ P
40: function REJECT(x)
41: Increment i(x)
42: if p_{x,i(x)} exists in Pref(x) then ▷ x wants to apply further
43: Enqueue(x, Q) ▷ x enters queue Q again
44: end if
45: end function
3.3.1 Multi-Round Scenario

Many candidates who obtain seats in the first round of seat allocation will surrender or reject their respective seats at a later stage. In order to utilize these surrendered seats, the business rules allow multiple rounds of seat allocation. We now present Algorithm 2 that incorporates the following two issues — the first issue arises due to multiple round and the second issue arises due to multiple candidates with same rank competing for a program.$^1$

- **Seat guarantee in future rounds.**
  Credentials (such as birth category, or qualifying marks) of candidates may change (due to faulty reporting) during future rounds. In some cases, fresh candidates become eligible to participate between rounds. In such situations, we need to provide seat guarantee to candidates who were allotted a seat in an earlier round. We introduce the idea of Min-Cutoff $(p)$ for each $p \in P$: this quantity is used in second and later rounds of allocation (see Chapter 5 for details). Intuitively, a candidate with rank better than, or as good as Min-Cutoff $(p)$ will never be rejected by $p$ regardless of the capacity of $p$. Candidates offered a seat in the first round will thus be no worse off in subsequent rounds. As alluded above, there might be new candidates who become eligible for seat allocation in subsequent rounds.$^2$

- **Multiple candidates with equal rank.**
  Suppose multiple candidates obtain exactly the same rank. In the situation when we are forced to reject some candidate due to the possibility that the program is oversubscribed, we have to also reject (and remove) all other candidates in the waiting list who also have the same rank. This may not be always possible.

  We carry out suitable modifications as stated in Algorithm 2 to allow such candidates to obtain seats in the program on a supernumerary basis. We keep WaitList$(p)$ fully ordered at each step, by choosing an arbitrary order between candidates in WaitList$(p)$ who have the exact same rank as per Merit$(p)$.

  There are two concepts involved here. First, when an attempt is made to remove a candidate $x$, a removal of all candidates with the same rank of $x$ may cause the waitlist which is initially overflowing, to now underflow. To identify this situation, we compute the length $G$ of the waitlist, and the length $L$ of the list of candidates all of whom have the same rank as $x$. If the difference between the two exceeds or matches the capacity, we are free to remove all such candidates. Second, if this condition is not satisfied, it is not possible to remove all candidates with rank of $x$.

The pseudocode of Algorithm 2 allows for additional optional inputs in order to implement second and later rounds of seat allocation. In Chapter 4, we show how various business rules of IITs and NITs (such as handling quotas, supernumerary seats for DS candidates, etc.) can be incorporated seamlessly in this algorithm. The full description of how to use Algorithm 2 to implement the seat allocation in each round is provided in Chapter 5.

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$^1$In 2015, similar issues had more complicated business rules; see $^3$ severely complicating the algorithm.

$^2$For example, a candidate might be ineligible for joint seat allocation earlier due to less board marks, but may become eligible in subsequent round if her board marks increase after re-evaluation. In such cases, the allocated seat shall be what the candidate would have got on the basis of the revised rank in the first round. This seat can be a supernumerary seat.
Algorithm 2 Deferred Acceptance (Full version allowing multiple rounds and multiple candidates with the same rank)

INPUTS:
Candidates $\mathcal{A}$, Programs $\mathcal{P}$
For each $x \in \mathcal{A}$:
Preference list $\text{Pref}(x)$
Optional input: integer $i(x)$. Default value $i(x) = 1$. (Start from beginning of preference list by default.)
For each $p \in \mathcal{P}$:
Capacity $c(p)$ and merit list $\text{Merit}(p)$.
Optional input: $\text{WaitList}(p)$.
Optional input: $\text{Min-Cutoff}(p)$. 0 by default.
Optional input: $\mathcal{Q}$ a queue of candidates. By default contains all candidates $x$ with $\text{Length}(\text{Pref}(x)) > 0$.

OUTPUTS:
For each candidate $x \in \mathcal{A}$, the allocation $\mu(x) \in \mathcal{P} \cup \{\emptyset\}$ and $i(x)$.
Also for each program $p \in \mathcal{P}$, the list of admitted candidates $\text{WaitList}(p)$

1: for all $p \in \mathcal{P}$ do
2: Create an empty ordered list $\text{WaitList}(p)$ that will consist of
3: candidates ordered by their rank in $\text{Merit}(p)$
4: end for
5: Create an empty queue $\mathcal{Q}$
6: for all $x \in \mathcal{A}$ do
7: $i(x) \leftarrow 1$ ▷ Initialize list position to 1.
8: if $\text{Length}(\text{Pref}(x)) > 0$ then
9: $\text{Enqueue}(x, \mathcal{Q})$ ▷ $x$ enters queue $\mathcal{Q}$
10: end if
11: end for
12: while $\mathcal{Q}$ is non-empty do
13: $x \leftarrow \text{Dequeue}(\mathcal{Q})$ ▷ $x$ is any candidate removed from queue $\mathcal{Q}$
14: $p \leftarrow p_{x,i(x)}$ ▷ $x$ applies to program $p_{x,i(x)}$
15: if $x$ is not eligible for $p$ OR $c(p) = 0$ then
16: $\text{Reject}(x)$
17: continue ▷ move to next person in $\mathcal{Q}$
18: end if
19: Insert $x$ into ordered list $\text{WaitList}(p)$ at correct location
20: if $\text{Length}(\text{WaitList}(p)) \leq c(p)$ then continue ▷ space in program
21: end if
22: $y \leftarrow$ Last candidate in $\text{WaitList}(p)$
23: if $\text{rank}(y) > \text{MinCutOff}(p)$ then $\text{RemoveAndReject}(y, p)$
24: end if
25: end while
for all $x \in \mathcal{A}$ do 

if $i(x) \leq \text{Length(Pref}(x))$ then 

$\mu(x) \leftarrow p_{x,i(x)}$

else $\triangleright x$ reached the end of her list 

$\mu(x) \leftarrow \emptyset$

end if 

end for 

return $\mu(x), i(x)$ for all $x \in \mathcal{A}$ and WaitList($p$) for all $p \in \mathcal{P}$ 

function Reject($x$) $\triangleright$ The function is assumed to have access to $i(x)$, Pref($x$), $Q$

Increment $i(x)$ 

if $i(x) \leq \text{Length(Pref}(x))$ then $\triangleright x$ wants to apply further 

Enqueue($x, Q$) $\triangleright x$ enters queue $Q$ again 

end if 

end function 

function REMOVEANDREJECT($w, p$) 

$G \leftarrow |\text{WaitList}(p)|$

$L \leftarrow$ number of people with rank same as $w$ $\triangleright L$ is at least 1 

if $(G - L) \geq c(p)$ then 

for all $x \in \text{WaitList}(p)$ with RANK($x, p$) = RANK($w, p$) do 

Remove $x$ from WaitList($p$) 

Reject($x$) 

end for 

end if 

end function
Chapter 4

Business Rules

As discussed earlier, the Government of India recognizes quotas for certain birth categories. In general, a candidate applies for a program rather than for a seat in a particular category; she may be eligible for multiple seat categories. The so-called business rules describe how to allocate seats in such scenarios. In this and subsequent sections, we describe how these rules are to be incorporated into the proposed algorithm. The following is a broad classification of the variety in allocation.

1. Allocations based on reservations based on birth-categories.
2. Allocations for persons with disabilities (PwD).
3. Allocations for candidates who are not nationals of India (International students). This particular section applies only to the IITs.
4. Allocations for certain children of military personnel killed in military operations (DS candidates). This particular section applies only to the IITs.
5. Allocations for candidates who fail to clear certain minimum thresholds but can be groomed for admission a year later (preparatory course (PC) candidates). This particular section applies only to the IITs.
6. Allocations based on reservations on the residency state of a candidate. This particular section does not apply to the IITs.
7. Allocations based on de-reservation of seats.
8. Allocations incorporating the rule of supernumerary seats for female candidates.

Allocations based on de-reservation of seats (Item 7), is presented in full details in Chapter 6. Allocation incorporating the rule of supernumerary seats for female candidates (Item 8) is presented in Chapter 7. In the current chapter we describe how our DA algorithm can incorporate Items 1-6.

4.1 Incorporating Quotas

We first consider the important cases of 1-2 above.
4.1.1 Virtual programs

All candidates, irrespective of their respective categories, declare programs in the decreasing order of preference. However, internally we introduce virtual programs based on the quota for each category. Each virtual program will be associated with a merit list constructed out of rank lists (which in turn is based on marks obtained in the exam). Each candidate will now be associated with a virtual preference list. The concept of virtual programs, together with virtual merit lists and virtual preference lists for candidates is the suggested way for handling the majority of business rules.

There are 8 virtual programs for each actual program as per Table 4.1. The DS virtual program for the IITs is considered later (Section 4.3).

| Category | PD Status | Preference List |
|----------|-----------|-----------------|
| GEN      | N         | OP              |
| OBC      | N         | OP > OBC        |
| SC       | N         | OP > SC         |
| ST       | N         | OP > ST         |
| GEN      | Y         | OP > OP-PD      |
| OBC      | Y         | OP > OP-PD > OBC |
| SC       | Y         | OP > OP-PD > SC |
| ST       | Y         | OP > OP-PD > ST |

Table 4.1: Candidates are partitioned into categories and assigned a tag. A candidate can possess only one of these 8 tags. Further, for each actual program, there is a separate virtual program corresponding to each of these 8 categories.

4.1.2 Virtual Preference List

The sequence of seat allocation mentioned in Rule VII of [8] are very important. These are given in Figure 4.1 and merit careful consideration. For example, the sixth row states that for an OBC-NCL candidate with PwD tag, we try to fill the OPEN seats before any other seat, failing which we consider the OPEN-PwD seat before venturing into OBC-NCL seats.

![Preference List Table](#)

Figure 4.1: Virtual preference list for candidates when quotas are involved.

---

\(^{1}\)In this and all further preference tables, OP, OBC and PD are used instead of OPEN, OBC-NCL and PwD respectively. That is, OP refers to OPEN, OBC refers to OBC-NCL, OBC-PD refers to OBC-NCL-PwD, etc.
4.1.3 Virtual Merit Lists

**Standard Rank Lists** How does one decide on which candidate to award a seat if there are competing candidates for a program? Associated with each virtual program is a merit list constructed from ranks provided by various examinations.

Quoting rule VI from [8] the following TYPES of rank lists will be prepared based on pre-defined cut-offs:

1. Common rank list (CRL): It includes candidates who are assigned the tag GEN, GEN-PwD, OBC-NCL, OBC-NCL-PwD, SC, SC-PwD, ST or ST-PwD. Foreign nationals are also included in the CRL prepared based on JEE (Advanced) 2018.
2. OBC-NCL rank list: It includes candidates who are assigned the tag OBC-NCL or OBC-NCL-PwD.
3. SC rank list: It includes candidates who are assigned the tag SC or SC-PwD.
4. ST rank list: It includes candidates who are assigned the tag ST or ST-PwD.
5. CRL-PwD rank list: It includes candidates who are assigned the tag GEN-PwD, OBC-NCL-PwD, SC-PwD or ST-PwD.
6. OBC-NCL-PwD rank list: It includes candidates who are assigned the tag OBC-NCL-PwD.
7. SC-PwD rank list: It includes candidates who are assigned the tag SC-PwD.
8. ST-PwD rank list: It includes candidates who are assigned the tag ST-PwD.

Once rank lists are available, the rules for allocation for various seat categories are specified in Rule VII of [8].

In each virtual queue, candidates with differing tags are eligible to participate. Thus in the OPEN virtual programs, we can find candidates with different categories from Table 4.1. The virtual merit list encodes the order of consideration for seats in each program.

4.1.4 Preparatory courses allocation

The notion of PC (Item 5 at the beginning of Chapter [4] for the IITs, will, however, uncover why only the standard merit lists are not sufficient in allocating seats. Quoting Rule XI of [8] we have the rules for seat allocation to preparatory courses applicable for every round.

1. Unfilled OPEN-PwD seats will be allocated to candidates in the CRL-PwD preparatory rank list subject to no more candidates in the CRL-PwD rank list having opted for them.
2. Unfilled OBC-NCL-PwD seats will be allocated to candidates in the OBC-NCL-PwD preparatory rank list subject to no more candidates in the OBC-NCL-PwD rank list having opted for them.
3. Unfilled SC-PwD seats will be allocated to candidates in the SC-PwD preparatory rank list subject to no more candidates in the SC-PwD rank list having opted for them.
4. Unfilled ST-PwD seats will be allocated to candidates in the ST-PwD preparatory rank list subject to no more candidates in the ST-PwD rank list having opted for them.

5. Unfilled SC seats will be allocated to candidates in the SC preparatory rank list subject to no more candidates in the SC rank list have opted for them.

6. Unfilled ST seats will be allocated to candidates in the ST preparatory rank list subject to no more candidates in the ST rank list have opted for them.

In order to allot seats to PC candidates, preparatory rank lists may be prepared. This leads us to the following definition.

**Definition 2.** We construct the extended merit list for any virtual program, cf. Table 4.1, by taking the standard rank list followed by the corresponding preparatory course (PC) rank list if

- such a list has been prepared, and
- the corresponding preparatory course exists.

Up to six lists are possible: PC-CRL-PwD, PC-OBC-NCL-PwD, PC-SC, PC-SC-PwD, PC-ST, PC-ST-PwD. In each case, if the PC list is prepared, it is included as part of the extended merit list for the parent category: e.g., if the PC-SC rank list is prepared, the virtual merit list for SC courses (in institutes that have PC courses) will include the SC rank list followed by the PC-SC rank list. This will automatically lead to unfilled seats being offered to PC candidates. Note that the PC rank lists do not have any commonality with the standard rank lists, i.e., a candidate in PC rank list will not appear in any standard rank list.

In summary, at this juncture, in the case no PC exists for a program (as is the case of the NITs), the virtual merit list of a virtual program is identical to the corresponding standard rank list. On the other hand, if PC courses are present, the virtual merit list of a virtual program is identical to the extended merit list.

Later on, we will see more complex virtual merit lists.

4.1.5 Updated Algorithm: DA With Quotas

Armed with virtual programs, virtual merit lists corresponding to virtual programs, and virtual preferences, we now explicitly construct the internal preference list for each candidate.

**Example 3.** Consider a candidate with category tag SC-PwD, who is eligible for both the SC virtual program, and the SC-PwD virtual program. This candidate has not cleared the cutoff specified for OPEN seat. Then for each IIT program $p$ in the preference list of the candidate, we instantiate the virtual preference from Figure 4.1 by excluding the OPEN option, and considering only the three other options corresponding to row 7.

Algorithm 2 is run for each round based on the construction of the virtual preference list for all candidates, and extended merit list for each virtual program.

It is important to note that by modifying the virtual preference tables, the standard DA with quotas can be applied based on variations in business rules on how quotas should be administered when, for example, unfilled seats are found.
4.2 DA with International Students

The business rules for the IITs specify that international candidates can be admitted to programs in IITs through supernumerary seats subject to the following constraints.

1. Eligibility: The candidate (with international student credentials) must have a valid rank in CRL and satisfy all the eligibility requirements meant for a GEN category candidate. Furthermore, such a candidate is eligible for a program if her rank is not worse than the rank of the worst rank Indian candidate in OPEN category getting admitted to that program. However, if there is any OPEN seat lying vacant in a program, then every international candidate is eligible for that program.

2. As per rules, the total number of international allocations must not exceed 10% of the total allocations in an academic program. However, each IIT may choose to restrict the seats for such candidates to any number below 10% in some, or all programs. There is a separate seat matrix provided by IITs for international candidates each year. This seat matrix is provided as input along with the usual seat matrix which is meant for Indian (i.e., non-international) students.

In order to incorporate this business rule, we proceed as follows. First, corresponding to each OPEN program, we introduce a virtual program for international candidates, with a capacity decided by each institute. Next, we compute the seat allocation only for Indian candidates using Algorithm 2. Then we process all international candidates. In order to satisfy the eligibility criteria mentioned in Item 1 above, we replace lines 15 to lines 18 in Algorithm 2 by the following code. Here OPEN\((p)\) is the OPEN virtual program for Indian candidates corresponding to the international virtual program \(p\).

\[
\begin{aligned}
1: & \text{ if } c(p) = 0 \text{ then} \\
2: & \quad \text{Reject}(x) \\
3: & \quad \text{continue} \\
4: & \text{ end if} \\
5: & \text{ if } \text{Length}(\text{WaitList}(\text{OPEN}(p))) \geq c(\text{OPEN}(p)) \text{ then} \quad \triangleright \text{OPEN}(p) \text{ had no vacancy} \\
6: & \quad y \leftarrow \text{Last INDIAN candidate in } \text{WaitList}(\text{OPEN}(p)) \\
7: & \text{ if } \text{Rank}(x,p) > \text{Rank}(y,p) \text{ then} \quad \triangleright x \text{ has inferior rank than } y \\
8: & \quad \text{Reject}(x) \\
9: & \quad \text{continue} \\
10: & \text{ end if} \\
11: & \text{ end if}
\end{aligned}
\]

4.3 DA with candidates from defense service quota

The business rule specifies that DS (defense services) candidates should be given the best program they prefer in an IIT subject to the constraint that there are only 2 seats for DS candidates per IIT. Moreover, these seats will be supernumerary seats. Note that for a DS candidate to be eligible for virtual DS program, she must have a valid rank in CRL.
4.3.1 Incorporating the business rule for DS candidates

To implement the rule, a new virtual DS program with capacity 2 is created for each IIT, namely IITK-DS, IITB-DS, IITR-DS, and so on. Only DS candidates are eligible for this virtual program. Furthermore, the preference list of each DS candidate is modified as follows. If the preference list of the DS candidate is \((p_1, p_2, p_3)\), then her preference list will first be modified as \((p_1, \text{Institute}(p_1), p_2, \text{Institute}(p_2), p_3, \text{Institute}(p_3))\), where \(\text{Institute}(p_i)\) is the DS virtual program created for the IIT corresponding to \(p_i\). For example, if \(p_i\) is a program in IIT Roorkee, then \(\text{Institute}(p_i)\) is IITR-DS. Then \(p_1\) (likewise \(p_2, p_3\)) will be replaced as usual by the list of virtual programs of \(p_1\) for which the DS candidate is eligible based on the birth category and PwD status. This ensures that each DS candidate first competes to get a program of some IIT based on birth category and PwD status, and only after that, she competes (based on rank in CRL) to get that program through DS rule. DS candidates admitted to, for example, the IITR-DS virtual program, are allotted a supernumerary seat in their most preferred program at IIT Roorkee.

4.4 DA for Admission into IITs, NITs, and other GFTIs

In Section 4.1.5 we have seen the standard DA with quotas which is applicable to all central government funded institutions. Further, we have seen various business rules, and how the core algorithm is modified to take care of various business rules. In this section we summarize the process of allocation.

4.4.1 Virtual Preference Table for IITs

Business Rule items 1-5 and items 7 & 8 from the list at the beginning of Chapter 4 apply. To include PC candidates, Figure 4.1 is modified slightly and is presented in Figure 4.2. Notice that, as compared to Fig. 4.1, there are new types of categories in the last six rows, and the extended merit list comes into play. We may use the Standard DA algorithm with quotas (Section 4.1.5) with the discussions so far in Sec. 4.2 and Sec. 4.3 if only seats in the IITs are offered.

In reality, a candidate may be eligible to apply for many programs across multiple institutions beyond the IITs. The virtual preference lists need to be considered in an appropriate fashion, depending on whether a program is in the IITs or not. The next two sections describe the process for NITs and other GFTIs.

4.4.2 Virtual Preference Table for NITs

All items in the beginning of Chapter 4 apply, except Items 3, 4, and 5. There are, however, additional qualifiers corresponding to Item 6. We focus on Item 6. Seats for academic programs offered by NITs are divided into Home State quota and Other States quota. These additional quotas are reflected in the virtual preference table as shown in Figure 4.3 and do not change the core of the algorithm.

Example 4. As an example, consider the virtual preference list for an OBC-NCL-PwD person whose “Home State” is Maharashtra. He may express a preference to apply to the electrical
| Category | PD Status | Preference List |
|-----------|-----------|-----------------|
| GEN       | N OP      | OBC             |
| OBC       | N OP >    | SC              |
| SC        | N OP >    | ST              |
| ST        | N OP >    | OP-PwD          |
| GEN       | Y OP >    | OP-PwD > OBC    |
| OBC       | Y OP >    | OP-PwD > SC     |
| SC        | Y OP >    | OP-PwD > ST     |
| ST        | Y OP >    | OP-PwD > PC(SC) |
| PC(SC)    | N SC      | PC(ST) N ST     |
| PC(ST)    | Y OP-PwD >| SC > PC(GE) Y OP-PwD |
| PC(OBC)   | Y OP-PwD >| OBC-PwD         |
| PC(GE)    | Y OP-PwD  |                 |

Figure 4.2: Virtual preference list for candidates when PC candidates are involved.

Engineering program of NIT in this state, viz., the NIT in Nagpur. In this case, her virtual preference will be represented by the sixth row in the table. If her next preference is the electrical engineering program of the NIT in Tamil Nadu, then the virtual preference will be read from the 14th row of the table and he will not be eligible for the Home State quota of the NIT in Tamil Nadu. Finally, if her next preference is the electrical engineering program in IIT Roorkee, Item 6 does not apply; we refer back to the sixth row in Figure 4.2.

4.4.3 Virtual Preference Table for Other GFTIs

For Government Funded Technical Institutions (GFTIs) other than the IITs and the NITs, all items in the beginning of Chapter 4 except for Items 3, 4, and 5 apply. On the basis of the existence of quotas based on the residency state of a candidate, there are the following three types of other GFTIs and their respective virtual preference tables.

1. All India (AI) quota: If a GFTI has only AI quota, then the virtual preference table is the same as the one shown in Figure 4.1. All Indian Institutes of Information Technology (IIITs) have AI quota only. Other examples of GFTIs that have only AI quota are School of Planning & Architecture, Bhopal and Gurukula Kangri Vishwavidyalaya, Haridwar.

2. Home State (HS) and Other State (OS) quota: If a GFTI has HS and OS quota, then the virtual preference table is the same as that for NITs (shown in Figure 4.3). BITS Mesra is one such GFTI that follows the HS/OS quota model.

3. Home State (HS) and All India (AI) quota: The virtual preference table for such GFTIs is shown in Figure 4.4. Currently Assam university, Silchar is the only GFTI institute having HS and AI quota.
| Category       | Which State | Preference List                                      |
|----------------|-------------|------------------------------------------------------|
| GEN            | Home        | OP.Home                                              |
| OBC            | Home        | OP.Home > OBC.Home                                   |
| SC             | Home        | OP.Home > SC.Home                                    |
| ST             | Home        | OP.Home > ST.Home                                    |
| GEN_PwD        | Home        | OP.Home > OP-PwD.Home                                |
| OBC_PwD        | Home        | OP.Home > OP-PwD.Home > OBC.Home > OBC-PwD.Home     |
| SC_PwD         | Home        | OP.Home > OP-PwD.Home > SC.Home > SC-PwD.Home       |
| ST_PwD         | Home        | OP.Home > OP-PwD.Home > ST.Home > ST-PwD.Home       |
| GEN            | Other       | OP.Other                                             |
| OBC            | Other       | OP.Other > OBC.Other                                 |
| SC             | Other       | OP.Other > SC.Other                                  |
| ST             | Other       | OP.Other > ST.Other                                  |
| GEN_PwD        | Other       | OP.Other > OP-PwD.Other                              |
| OBC_PwD        | Other       | OP.Other > OP-PwD.Other > OBC.Other > OBC-PwD.Other  |
| SC_PwD         | Other       | OP.Other > OP-PwD.Other > SC.Other > SC-PwD.Other   |
| ST_PwD         | Other       | OP.Other > OP-PwD.Other > ST.Other > ST-PwD.Other   |

Figure 4.3: Virtual preference list for candidates for seats in the NITs. The first 8 rows represent preferences of candidates applying to the NIT in their “Home State” quota; seats in this quota are available only to state residents. Candidates applying to a NITs in \( \nu \) which is not their home state quota (the last 8 rows) will compete with all residents of India, excluding candidates whose home state is \( \nu \), the state under consideration.
As an example, consider the virtual preference list for a ST-PwD person whose “Home State” is Assam. She may express a preference to apply to the mechanical engineering program of Assam University Silchar. In this case, her virtual preference list for this program will be represented by the ST-PwD row (the eighth row) in the table shown in Figure 4.4. Let us consider an OBC-NCL-PwD candidate whose Home State is not Assam. If one of her preferences is a program in the Assam University Silchar, then the virtual preference list for this program will be read from the fourteenth row of the table shown in Figure 4.4. Note that not only will she be ineligible for the seats in the Home State quota of this university, she will also be competing for seats from All India quota with candidates whose home state is Assam.

### 4.4.4 Summary

The core algorithm is the standard DA algorithm with quotas. However, the virtual preference lists must be correctly constructed based on the programs a candidate applies to, and the tag she has. Once virtual programs, virtual preference lists, and virtual merit lists are constructed, the algorithm is applied for all candidates in the pool, including the PC candidates, DS candidates, international students, as well as the remaining bulk of candidates who do not belong to these special cases.

Note that the business rules involve complex de-reservation. As such, in order to complete the allocation, de-reservation as per business rules must be employed on top of the process described so far. Chapter 6 is devoted to handling de-reservation in a holistic way. Starting from 2018, the rule of supernumerary seats for females has also been introduced. We discuss it in Chapter 7.
| Category  | Which State | Preference List |
|-----------|-------------|-----------------|
| GEN       | Home OP.AI > | OP.HS           |
| OBC       | Home OP.AI > | OBC.AI > OP.HS > OBC.HS |
| SC        | Home OP.AI > | SC.AI > OP.HS > SC.HS |
| ST        | Home OP.AI > | ST.AI > OP.HS > ST.HS |
| GEN_PwD   | Home OP.AI > | OP-PwD.AI > OP.HS > OP-PwD.HS |
| OBC_PwD   | Home OP.AI > | OP-PwD.AI > OBC.AI > OBC-PwD.AI > OP.HS > OP-PwD.HS > OBC.HS > OBC-PwD.HS |
| SC_PwD    | Home OP.AI > | OP-PwD.AI > SC.AI > SC-PwD.AI > OP.HS > OP-PwD.HS > SC.HS > SC-PwD.HS |
| ST_PwD    | Home OP.AI > | OP-PwD.AI > ST.AI > ST-PwD.AI > OP.HS > OP-PwD.HS > ST.HS > ST-PwD.HS |
| GEN       | Other OP.AI  |                 |
| OBC       | Other OP.AI > | OBC.AI         |
| SC        | Other OP.AI > | SC.AI          |
| ST        | Other OP.AI > | ST.AI          |
| GEN_PwD   | Other OP.AI > | OP-PwD.AI     |
| OBC_PwD   | Other OP.AI > | OP-PwD.AI > OBC.AI > OBC-PwD.AI |
| SC_PwD    | Other OP.AI > | OP-PwD.AI > SC.AI > SC-PwD.AI |
| ST_PwD    | Other OP.AI > | OP-PwD.AI > ST.AI > ST-PwD.AI |

Figure 4.4: Virtual preference list for candidates for seats in certain other GFTIs. The last 8 rows represent preferences of candidates applying to the GFTI not in their “Home State” (HS); seats in this quota are available to all Indian nationals. Candidates applying to a GFTI in their home state (the first 8 rows) will first be considered for seats in the All India (AI) quota failing which they will be considered for seats in the Home State quota.
Chapter 5

Multi-round Implementation

Allocation of seats is conducted over multiple rounds for a variety of reasons, including the reality that offered seats may not be accepted, and overbooking of seats is not permitted. As introduced in Section 3.3.1, the notion of fairness becomes complicated since new candidates may join the seat requisition process. Second and later rounds facilitate the utilization of surrendered seats, including the possibility of awarding a surrendered open category seat to a person earlier denied such an open seat, and earlier awarded a seat in a particular restricted quota. To maintain truthfulness, fairness, and optimality across rounds requires careful algorithmic design.

After initial information collection (Section 3.1) our algorithm proceeds in rounds with the following activities taking place in each round.

1. We execute the algorithm described in Section 4.4 using Algorithm 2 with the candidates initiating applications (proposing to the programs in the decreasing order of their preferences). Such an execution is termed as a run of the algorithm. The seat allocation computed by the algorithm is announced to the candidates.

2. A candidate who is allotted a program is required to go physically to a reporting center for document verification and seat confirmation in the program. There, the candidate may also exercise the options ‘freeze’, ‘float’, or ‘slide’ for future rounds. These options are described in more details later. A candidate who accepts a program may also surrender her seat and withdraw from the joint seat allocation later in the same round or any subsequent round before the withdrawal deadline. It is also possible that after document verification, the credentials of the candidate change which may potentially lead to the cancellation of the seat of the candidate. A candidate may reject the offered seat; rejection is implicit if the candidate does not report. Candidates who reject a seat do not participate in the process thereafter.

3. Based on the activities at the reporting center, inputs for the next round of seat allocation is updated.

Withdrawal was allowed till the sixth round in 2018.
5.1 MRDA

The process described in Steps 1–3 is summarized in Figure 5.1 and it constitutes the Multi Round Deferred Acceptance scheme. The process mentioned here does not take care of de-reservation which is addressed in Chapter 6. In brief, in de-reservation, multiple runs of the algorithm in Step 1 are performed, and we term the modified version as the Multi Run DA algorithm, MRDA.

“Multi-Round” is a term that refers to the overall mechanism that occurs over days and possibly weeks, with the repeated involvement and inputs of humans, especially the candidates. In the context of a mechanism, the acronym MR in MRDA may actually be considered to refer to Multi-Round Deferred Acceptance scheme. These two concepts – run and round – are orthogonal: one can perform multiple runs of the DA in situations where only one round is planned, and de-reservation is necessary; that would be a multi-run deferred acceptance algorithm. One could also perform a single run per round, and have multiple rounds, and run the algorithm as in Figure 5.1; this would be a multi-round scheme. Or one could do both, as performed in the joint seat allocation every year since 2015. In terms of nomenclature, we choose not to distinguish between these cases as the intent is clear from the context.

![Figure 5.1: Multi-round deferred acceptance allocation.](image-url)
5.2 Input for second and subsequent rounds

Apart from seat matrices which remain unchanged throughout all the rounds of seat allocation, the following input files are updated due to the reporting center activities of each round. These updated tables are to be used for seat allocation in subsequent rounds.

1. **Candidate Table**
   The credentials of the candidates may change during the document verification at the reporting center during a round. The credentials are updated accordingly in Candidate table for the next round. In addition, a candidate who is offered a seat may opt for Freeze/Slide/Float/Reject for the seat allocation in subsequent rounds. This information is updated in the Candidate table. Candidates who become ineligible for seat allocation after document verification are removed from the Candidate table in subsequent rounds.

2. **Preference list:** Based on the changes in the credentials of a candidate, the preference list of the candidate may have to be updated. In particular, some choices may become invalid after document verification. (The rules for these are tabulated in the business rules, but suffice to say that this step is necessary).

3. **Previous Round Allotment.**
   The Allotment Table is one of the output files of the seat allocation algorithm after each round. Details about the program allotted to a candidate appear here. However, a candidate who is allotted a seat for the first time in the previous round might not report at the reporting center (thereby implicitly rejecting the offer). Another possibility is that a candidate after accepting a seat may surrender it and withdraw from the joint seat allocation. This additional information is appended to the Allotment table of the round. The Allotment table at the end of the previous round, is very crucial for computing the seat allocation for the next round. Hence, for the second and subsequent round, this table is also provided as an additional input file.

The reader is advised to study Section 10.2 in the Appendix to know more details of the activities that take place at reporting center and how the input files as mentioned above for the second (or subsequent) round are computed.

5.3 Preprocessing of input for second and subsequent rounds

Once the input for second (or any subsequent) round is received, it needs to be preprocessed before we carry out the seat allocation of the round. In particular, the following tasks need to be carried out (1) Editing preference list as mentioned above (2) Computing Min-CUTOFF, the minimum cut-off rank of each virtual program to ensure (as mentioned in Section 3.3.1) that no candidate abruptly loses an earlier awarded seat in a later round. We now describe how this preprocessing is carried out.

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2This table stores the credentials of the eligible candidates participating the joint seat allocation.
5.3.1 Preference list editing

Each candidate who is allocated a program in the previous round (call it $N$) chooses one of the following options before the next round ($N + 1$) is conducted. In each case we describe how the candidate’s preference list is appropriately edited before round $N + 1$. This edited preference list is then used to construct virtual preferences as usual.

- **Reject**: The candidate rejects the program. In this case, the choice list of the candidate is set to empty to remove the candidate from the process. (Note that this reference to *Reject* is different from the *Reject* in the algorithm pseudocode.)

- **Freeze**: The candidate confirms the acceptance of the program allocated. In this case, we leave the allotted program on her choice list along with the entries below the allotted program, and eliminate all other entries.

- **Float**: The candidate expresses that the program is acceptable but would like to be considered for future rounds to get a more desirable program, if possible. In this case, we leave the candidate choice list unchanged.

- **Slide**: The candidate wishes to be considered for future rounds but would prefer programs in the same institute where he is offered the current program. In this case, we remove all programs from his list that are above the current allotment and belong to the institute different from the institute of the program offered to him. The allotted program and the entries below the allotted program are left unchanged.

- **Withdraw**: The candidate withdraws from the joint seat allocation. In this case, the choice list of the candidate is set to empty. Although ‘Reject’ and ‘Withdraw’ ultimately have the same effect (the candidate will no longer be part of the process), the difference lies in the timing. Once a candidate is offered a program, and she accepts, she can later withdraw till the withdrawal deadline.

5.3.2 Computing Min-Cutoff

The seat guarantee across multiple rounds is needed because, as discussed above, the rules provide for a freeze, float, and slide option. The seat guarantee is implemented by the notion of Min-Cutoff: A candidate is allowed to retain a seat in round $J + 1$ if her rank is better off, or equal to the rank corresponding to the minimum cut-off rank in a virtual program at the end of $J$th round. This rank might be based on her rank, or, more subtly, the rank of any other candidate previously allotted a seat in the virtual program under consideration. Further, to avoid merit violation, the candidate may get something even better (from her perspective) in yet another program based on the minimum cut-off of that program, and this is permitted even on a supernumerary (SN) basis.

**Computing Min-Cutoff**: The word minimum in min-cut-off is used to indicate that in future rounds, the cutoff (or closing rank) can actually become worse (i.e., larger) than the

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3 In other words, the virtual preference list for the candidate now contains only virtual programs corresponding to the allotted program and programs ranked below it by the candidate, as per the relevant table (using the complete row corresponding to the candidate category).

4 Virtual preferences over virtual programs remain unchanged for programs that are not removed.
min-cut-off. Consider any virtual program \( p \). We use the output \( \text{WaitList}(p) \) of \( i \)th round to compute \( \text{MIN-CUTOFF}(p) \) for \((i+1)\)th round as follows. We temporarily construct a reduced waitlist for \( p \) by removing the following kinds of candidates:

1. Those who opted for reject or withdraw.
2. Those whose seat got cancelled at the reporting center in \( i \)th round.

We then set \( \text{MIN-CUTOFF}(p) \) for the next round as follows:

- If the reduced waitlist is non-empty, \( \text{MIN-CUTOFF}(p) \) is set to \( \text{RANK}(y,p) \), where \( y \) is the last candidate in the reduced wait list. Note again that, \( \text{RANK} \) here stores the extended merit list rank after revision\(^5\).
- If the reduced waitlist is empty, \( \text{MIN-CUTOFF}(p) \) is set to 0. Thus, nobody applying to \( p \) in the next round will get any min-cut-off benefit.

\[ \text{5.4 Summary} \]

We have described a multi-round deferred acceptance algorithm. After each round, candidates may reject, freeze, slide, or float with the program offered. As a result, the program allocated to a candidate in subsequent rounds may differ. In this case, it is guaranteed that the new program allocated to the candidate will be preferred (by the candidate) to the earlier one. Many other business rules have been incorporated using the concept of virtual programs, virtual preference lists, and virtual merit lists. To make all desirable effects happen between rounds, internally in the data structures, the choices of the candidates need to be modified and possibly their credentials may need to be changed.

\textbf{Remark: } Section \[10.5\] in the Appendix presents the complete implementation details of the generic MRDA algorithm along with all input-output formats. The reader interested in the actual implementation of the DA algorithm should refer to this section.

\[ \text{\textsuperscript{5}Recall Definition 2.} \] **Example:** If \( p \) is an OBC-NCL virtual program, then we use the last rank in the standard OBC-NCL merit list. On the other hand, if \( p \) is an SC virtual program then we use the last rank in the extended merit list, which, to recall is constructed by taking the SC rank list followed by the PC-SC rank list.
Chapter 6

De-reservations

Recall that the DA algorithm as described in Section 4.4 takes care of all business rule of categories as described in Chapter 4 except de-reservation. When seats are unfilled due to lack of candidates in a particular category, seats may be de-reserved.

After a possible allocation to preparatory candidates, if seats in one or more of OPEN-PwD, OBC-NCL-PwD, SC-PwD, ST-PwD seat categories are still vacant in any program, they are de-reserved. For example, unfilled SC-PwD seats (that are also not filled with PC candidates) will be de-reserved and treated as SC category seats for allocation in every round of seat allotment. Similarly, unfilled OBC-NCL seats will be de-reserved and treated as OPEN seats (there is no allocation to PC candidates in this case). However, unfilled SC and ST category seats will NOT be de-reserved.

The de-reservation rules stated above are succinctly depicted in Figure 6.1.

There are two methods of incorporating de-reservation rules. The first and a very simple method is to change the input seat capacities available in a seat matrix, and move unfilled seats to the appropriate category, and run Algorithm 2 using the revised seat matrix. This method involves multiple runs and has been used for the joint seat allocation since the year 2015. This method is described in the following section. The second method involves modifying the virtual preference lists and the virtual merit lists. This method, along with its advantages and disadvantages over the first method, is described in the earlier technical report [3].

6.1 Multi-Run DA with De-reservation

Multi-run DA may be viewed as running the method in Section 4.4 several times, each time updating the seat matrix provided as input by appropriately de-reserving seats that were not filled in the previous run.

6.1.1 Multi-Run DA Algorithm

The Multi-Run DA algorithm works as follows.

1. We run the algorithm in Section 4.4 with the appropriate table for the virtual preference list depending on the program a candidate applies to, and the corresponding simplified virtual merit list.
Figure 6.1: De-reservation. Starting from the bold arrow and following dotted arrows, one arrives at a possible sequence in which seats are de-reserved. For example, unfilled OPEN-PwD seats are considered to all eligible preparatory candidates (PC-OPEN-PwD); if at this stage, seats are still unfilled, they are offered to all eligible candidates (OPEN).

2. If there are unfilled seats that can be de-reserved, then we update the capacities by de-reserving unfilled seats to the parent category. We then re-run the algorithm as in Step 1 on all candidates.

If there are no unfilled seats that can be de-reserved, i.e., all unfilled seats are in OPEN or SC or ST virtual programs, then we terminate.

This algorithm enjoys monotonicity across runs: The options available to candidates are only enhanced in going from one run to the next. More seats become available in parent programs, whereas the programs that “lose” seats due to de-reservation do not hurt the allocation since there is no demand for those seats anyway (in that run or in any future run). Thus, candidates get the same or better allocation than before. Seats flow only upstream towards parent categories, cf. Figure 6.1. On tests consisting of various synthetic as well as the actual data during the joint seat allocation, the number of runs were always less than 5 in the last four years.

**Additional Output:** The primary purpose of the seat allocation algorithm is to allocate seats. However, in addition to the allocation of seats, we can output the opening and closing dates of programs.
ranks in the Multi-Run Multi-Round algorithm after the last round. We read off the opening rank for each category if there is any candidate in the virtual program. The closing rank is the rank of the last admitted candidate in the corresponding virtual program. However, if the corresponding candidate is from Preparatory Course, we use the following convention. We use the actual rank of the candidate in the corresponding Preparatory Course rank list and add the suffix P to it (to indicate “PC”). (Note that the extended merit list is for internal purpose only. Therefore, we must announce the actual Preparatory Course rank instead of extended merit list rank).

In addition, we also output the initial seat matrix, and the final seat matrix for each program, with unfilled seats marked. The final seat matrix is the matrix used in the final run of DA during which no further de-reservation occurred. The following example shows how to interpret the initial and final seat matrix together.

**Example 5.** Consider a program with:

- **Initial seat matrix:** 20 OPEN seats, 10 OBC-NCL seats, 2 OBC-NCL-PwD seats, and 1 OPEN-PwD seat. (Suppose there are no other seats.)
- **Final seat matrix:** 21 OPEN seats (18 filled), 11 OBC-NCL seats, 0 OBC-NCL-PwD seats and 1 OPEN-PwD seat (filled by PC candidate).

The immediate inference is that all 11 OBC-NCL seats in the final seat matrix are occupied, since if not, they would have been de-reserved. We also notice that the 1 OPEN-PwD seat is occupied by a PC candidate.

We further interpret the above starting at the lowest level of Figure 6.1. We infer that 2 OBC-NCL-PwD seats were both de-reserved to OBC-NCL, leading to 12 OBC-NCL seats. Of these OBC-NCL seats, 1 was unfilled (hence the final seat matrix contained 11 OBC-NCL seats), and further de-reserved to OPEN, leading to 21 OPEN seats. Finally, we infer that 3 of these OPEN seats were unfilled.
Chapter 7

Supernumerary seats for females

There are many institutes, such as the IITs, where the percentage of female students in the undergraduate programs used to be (until 2018) approximately 9% of the entire student population. Stakeholders in the system sought an increase in the gender ratio. The improvement in the ratio was to be carried out in a phased manner — at least 14% females in 2018, and thereafter, 17% in 2019 and 20% in 2020.

Until 2017, all seats in a virtual program were allocated in a gender-oblivious manner. One way to achieve the new objectives would be to declare a 14% reservation, similar to the reservations based on birth category as described earlier. This was not considered acceptable since many practical constraints that had to be satisfied. (See also Section 7.3.1) First, some programs already had more than 20% females already (even if the Institute did not). It was not considered acceptable to burden the institute with variable amount of new infrastructure requirements for the females: seat matrices (i.e., capacities) had to be announced before the process began. A related constraint was that the number of non-female candidates could not also be increased substantially, or decreased (so as to remove the perceived “injustice”) for that matter. One way to satisfy this requirement is that the number of non-females admitted should be close to their numbers in 2017 (to be more precise, average of the last few years) by dividing the pool into females and non-females. We direct the reader to Section 10.1 for more insights to some of the difficulties in reducing variability in the number of females admitted while retaining a modicum of fairness.

We describe how the MRDA algorithm, with suitable changes in the virtual programs and the virtual preference lists, can ensure at least 14% seats for females in 2018 and fairness for all candidates while satisfying the constraints stated above.

7.1 The Method

In order to implement the rule of supernumerary seats for females and respecting all the constraints, the proposed algorithm will require that each virtual program $p$ has two separate seat pools defined as follows:

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1In this chapter, a male or transgender candidate is considered as a non-female candidate.
2The institutes were already finding it difficult to create the infrastructure for additional females, so it was difficult for them to create the infrastructure for any additional non-females.
• Female-only\((p)\): This pool will be exclusively for females and they will be admitted on the basis of relative merit.

• Gender-neutral\((p)\): As the name suggests, this pool will admit candidates through merit, but without any gender bias.

The method of computing the number of seats in Female-only\((p)\) pool and Gender-neutral\((p)\) pool for each virtual program \(p\) is described in Section 7.3.

Now we describe the order in which candidates are considered for a seat in these two pools of a virtual program. It is this order that plays the key role in establishing the fairness properties of the algorithm.

7.1.1 Order of seat allocation

Consider a virtual program \(p\) in the choice list of a candidate \(c\). \(c\) will be considered for a seat in the virtual program \(p\) based on the gender as follows.

• If \(c\) is a female candidate: \(c\) will first compete for a seat from the Female-only\((p)\) pool. Only after she fails to get a seat from this pool, will she compete for a seat from Gender-neutral\((p)\) pool.

• If \(c\) is a non-female candidate: \(c\) will compete for a seat from the Gender-neutral\((p)\) pool only.

7.2 Fairness properties

The algorithm guarantees the following fairness properties.

Fairness for non-female candidates

• No reduction in the number of available seats.

As shown later in Section 7.3, the number of seats occupied by non-females in the gender neutral pool of an academic program \(p\) (e.g., IIT Kanpur CSE) in 2018 will be equal to or greater than the number of seats that the non-female candidates got in that program in 2017. So potentially all the seats of the gender-neutral pool of \(p\) may be allocated to non-females only.

• Guarantee of no-adverse effect.

The algorithm guarantees that at least one of the following properties will hold for each virtual program \(p\) (e.g., IIT Kanpur CSE SC category):

1. The allocation of all seats (the union of the gender-neutral pool and the female-only pool) of \(p\) is purely based on merit without any gender bias.

2. All gender-neutral seats of \(p\) are occupied by non-females only.

In order to better understand the second property stated above, we provide an example.
Example 6. Suppose the number of seats in the gender-neutral pool and the female-only pool of a virtual program, say IITK CSE SC, are declared as 10 and 2 respectively. The allocation produced by the algorithm will ensure the following. If less than 10 seats from the gender-neutral pool are occupied by non-female candidates, then all the 12 seats from IITK CSE SC are allocated on pure merit basis among all the SC candidates who competed for a seat in IITK CSE SC without any gender bias.

Fairness for female candidates

- The algorithm will guarantee that each academic program will have at least 14% female candidates.
- Under no circumstance will a female candidate be denied a seat in a virtual program while allocating the same seat to a non-female candidate with (i) equal or worse rank than her, and, (ii) satisfying the same eligibility criteria. (This property ensures that female candidates can still occupy more than 14% seats on the basis of merit).

7.2.1 Proof of the fairness properties

We shall now establish that the fairness properties mentioned above are indeed guaranteed by the algorithm. The first fairness property for non-females follows from the construction of seat matrices as shown in Section 7.3. We shall now establish the second fairness property for non-female candidates. Let $p$ be any virtual program (for example, IIT Kanpur Civil Engg. SC or NIT Surat Electrical Engg. Home State OBC_NCL). Recall that there are two seat pools of $p$ based on gender: Gender-neutral($p$) and Female-only($p$). We begin with the following two facts which follow immediately from the order in which female candidates are considered for seat allocation.

Fact 1: Among the females getting admitted to $p$, the top rankers occupy Female-only($p$) pool only. That is, those in the female-only pool will have higher ranks compared to those females in the gender-neutral pool.

Fact 2: Each female candidate applies to Gender-neutral($p$) only after failing to get a seat from Female-only($p$).

If there is no female occupying a seat in Gender-neutral($p$), then obviously all candidates occupying seats in Gender-neutral($p$) are non-females only. So, in order to establish the second fairness property for non-female candidates, we need to analyse the case in which at least one seat of Gender-neutral($p$) pool is occupied by a female candidate, say $c$. Recall that the seat allocation for Gender-neutral($p$) pool is carried out purely on merit basis without any gender bias/preference. This along with Fact 2 imply that rank of each candidate (including $c$) occupying a seat of Gender-neutral($p$) must be strictly better than the rank of each candidate who applied for a seat in $p$ but got rejected. Fact 1 and Fact 2 also imply that every female candidate occupying a seat from Female-only($p$) will have strictly better rank than that of $c$. Therefore, rank of each candidate who is allocated a seat from Gender-neutral($p$) pool or Female-only($p$) pool is strictly better than the rank of each candidate who applied but failed to
get a seat in $p$. Hence, if we had to carry out allocation of Gender-neutral($p$) $\cup$ Female-only($p$) seats on purely merit basis without any gender bias/preference among all the candidates who applied to $p$, the set of candidates getting allocated to $P$ will be identical to the current set of candidates occupying seat from Gender-neutral($p$) and Female-only($p$) pools. This implies the second fairness property for non-females.

To establish the fairness property for females, we proceed as follows. It follows from Fact 2 that every female candidate, after failing to get a seat from Female-only($p$) pool, competes for a seat from Gender-neutral($p$) pool. Further, each non-female candidate can apply for a seat of program $p$ from Gender-neutral($p$) pool only. Since seats are allocated from Gender-neutral($p$) pool purely on merit basis and without any gender bias/preference, so it can never happen that a female is denied a seat from $p$ but given to a non-female candidate with inferior rank.

The 14% constraint (for 2018) fairness property is satisfied by the seat capacities mentioned below. Hence we can conclude that all fairness properties claimed by our algorithm are indeed satisfied by it.

Note: In order to incorporate the rule of supernumerary seats for females, there are a couple of simple and intuitively appealing approaches, but each of them have one or more flaws. We illustrate these approaches in Section 10.1 of Appendix. We encourage the reader to study them in order to appreciate the non-triviality of the current algorithm.

### 7.3 Constructing the seat matrices for 2018

Consider an academic program $P$. Let us first define a few notations.

- $C$: Seat capacity of $P$ in 2017.
- $f$: Number of female candidates who were allocated program $P$ in 2017.

We first describe the procedure for computing the number of seats for Female-only($P$) and Gender-neutral($P$).

- If $f$ is less than 14% of $C$, we create $x$ additional seats for females according to the formula:

\[ f + x = 0.14(C + x) \]

This implies $x = (0.14C - f)/0.86$. Thus Female-only($P$) will have $f + x$ seats. In case $x$ is a fractional number, we need to consider its ceiling while rounding it. Gender-neutral($P$) will have $C - f$ seats.

- If $f$ is more than 14% of $C$ but less than or equal to 20% of $C$, then Female-only($P$) will have $f$ seats and Gender-neutral($P$) will have $C - f$ seats.

- If $f$ is more than 20% of $C$: In this case, Female-only($P$) will have $0.2C$ seats and Gender-neutral($P$) will have $0.8C$ seats.

Once the number of seats for Female-only($P$) and Gender-neutral($P$) have been computed for an academic program $P$ as described above, we need to distribute them among its virtual programs according the prevailing business rules as follows. For IITs which have only All India quota, there are eight virtual programs according to the respective categories - GEN, OBC, SC,
ST, and their PwD counterparts. For non-IIT institutes, there are two types of state quotas: Home State and Other State (or All India). So there are 16 virtual programs defined by the quota and categories for these institutes.

Note:

1. In case some JoSAA institute wishes to achieve female percentage in the range $[14\%, 20\%]$, replace 14% in the calculations above by the desired percentage.

2. In case of an academic program of capacity $C$ introduced for the first time in 2018, the number of seats in Female-only($P$) pool will be 14% of $C$ and the remaining seats will be in the Gender-neutral($P$) pool.

7.3.1 Supernumerary seats versus reservation for females

The creation and allocation of supernumerary seats for female candidates is fundamentally different from reservation of seats for female candidates and should NOT be mistaken for any kind of reservation for females.

Example 7. Suppose a program has 86 Gender-neutral seats and 14 Female-only seats. Further, let us assume that the top 14 rankers opting for the program are females and the next 86 rankers opting for the program are non-females.

In the current allocation scheme, the top ranking 14 females will first be allocated the 14 Female-only seats. The non-females will be allocated the 86 Gender-neutral seats.

In contrast, if the Female-only seats were following the allocation similar or equivalent to “reservations”, then the top ranking 14 females would first be allocated the top 14 Gender-neutral seats and therefore the remaining $86-14 = 72$ Gender-neutral seats would be allocated to non-females. Further, $14$ Female-only seats would be allocated to lower ranked females, thereby depriving the allocation of the program to the remaining $(86-72 = 14)$ higher ranked non-females.

In this example, with the “reservations” scenario, not only have we increased the infrastructure requirements for females, some non-females may perceive injustice when a superior scheme (such as the one described in this chapter) is possible.

7.4 Implementation details

The algorithm is implemented by an additional level of refinement for each virtual program. Recall that till now an academic program was split into various virtual programs on the basis of the category (total eight) and state quota (All India, Home State, Other State). A simple way to implement the rule of supernumerary seats for females is to split each virtual program on the basis of gender. For example, an earlier virtual program of IITs, say IIT Kanpur, CSE, OBC_NCL will be split into two virtual programs:

- IIT Kanpur, CSE, OBC_NCL, Gender-neutral
- IIT Kanpur, CSE, OBC_NCL, Female-only

Joint Seat Allocation Authority (JoSAA) is the authorized body for admissions ever since our algorithm was adopted.
Likewise, an earlier virtual program of CSAB institutes, say NIT Surat Civil Engineering Home State ST, will be split into the following two virtual programs:

- NIT Surat, Civil Engineering, Home State, ST, Gender-neutral
- NIT Surat, Civil Engineering, Home State, ST, Female-only

An important issue that needs to be considered for the implementation of the above algorithm is whether we need to give preference to category or gender while creating virtual preference list of a candidate. For example, if an OBC_NCL female candidate with a valid GEN rank applies for an academic program $P$, what should be the order that should be followed? The candidate will be first considered for a seat from the Female-only pool of GEN seats for program $P$ followed by Gender-neutral pool of GEN seats for program $P$. Thereafter, she will be considered for a seat from Female-only pool of OBC_NCL seats for program $P$ followed by Gender-neutral pool of OBC_NCL seats for program $P$. The justification for the above order is the following: The candidate is eligible for GEN seats. So attempts must be made to allocate her a GEN seat before considering her birth category or gender.

Once we have created gender based virtual programs, all we need to do is to create the virtual preference lists of each candidate based on gender as recommended by the algorithm. To illustrate this, we provide examples.

**Example 8.** Suppose $c$ is a female candidate belonging to the SC_PwD category with a valid rank in SC merit list and CRL. Suppose one of her choices is IIT Madras Chemical Engineering. Then we create the following virtual programs, in order:

1. IIT Madras, Chemical Engineering, GEN, Female-only
2. IIT Madras, Chemical Engineering, GEN, Gender-neutral
3. IIT Madras, Chemical Engineering, PwD, Female-only
4. IIT Madras, Chemical Engineering, PwD, Gender-neutral
5. IIT Madras, Chemical Engineering, SC, Female-only
6. IIT Madras, Chemical Engineering, SC, Gender-neutral
7. IIT Madras, Chemical Engineering, SC_PwD, Female-only
8. IIT Madras, Chemical Engineering, SC_PwD, Gender-neutral

**Example 9.** Suppose $c$ is a non-female candidate belonging to OBC_NCL category with a valid rank in CRL. Suppose one of his choices is IIT Indore Electrical Engineering. Then we create the following virtual programs, in order.

1. IIT Indore, Electrical Engineering, GEN, Gender-neutral
2. IIT Indore, Electrical Engineering, OBC_NCL, Gender-neutral

**Example 10.** Suppose $c$ is a female candidate belonging to ST category. Suppose one of her choice is NIT Surat Civil Engineering. Suppose her home state is Gujarat. Then we create the following virtual programs, in order. 

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The following additional points are very crucial in incorporating the rule of supernumerary seats for females.

- **Vacant seats**
  Vacant seats, if any, from the female-only virtual program, is not to be filled by any non-female candidate. The justification for this rule is the following: In this case, all seats from Gender-neutral(p) will be occupied by non-female candidates, satisfying the fairness property for them. Seats from Female-only pool may have supernumerary seats created for improving gender ratio only. De-reserving these seats for non-females will defeat the purpose of supernumerary seats for females.

- **Handling foreign candidates** [for IITs only]
  Foreign candidates will be admitted in gender-oblivious manner only. Each foreign candidate will be considered for an IIT program if his/her rank is the same or better than the rank of the closing rank of the corresponding Gender-neutral OPEN virtual program.

- **Handling DS candidates** [for IITs only]
  Recall that there are 2 supernumerary seats for DS candidates in each IIT. These seats will be gender-neutral only.

- **Handling Preparatory Course candidates** [for IITs only]
  Preparatory course candidates will be handled based on the gender. For example, any vacant seat from a Female-only virtual program will be offered only to Preparatory Course female candidates corresponding to that virtual program. Likewise, any vacant seat from a Gender-neutral virtual program will be offered to all Preparatory Course candidates eligible for that virtual program.
Chapter 8
Reduction of Vacancies

As alluded in the introduction, joint seat allocation provides several advantages to the student, including a single admission window, an aligned academic calendar, and a fair allocation. These beneficial logistical advantages of having a single admission window is hard to quantify in a nation as large as India.

In this chapter, we discuss a subset — the impact of the joint seat allocation in terms of provable reduction in vacancies in the IITs compared to 2014, and leading up to 2018. Since IIT seats are coveted by a vast majority of engineering aspirants, any reduction is substantially beneficial. We discuss the vacancies in IITs in Section 8.1 and the vacancies in NITs, IIITs and other GFTIs (henceforth non-IITs) in Section 8.2.

8.1 Vacancies in the IITs

Table 8.1 lists the vacancies over the years\footnote{2018 vacancy data was not available at the time of writing this report.} and the discernible trend is the reduction in vacancies even when the number of seats have increased. An increase in the number of seats should normally result in increase in vacancies, especially since the newer IIT\footnote{The Indian School of Mines, Dhanbad (ISM) was designated an IIT in 2016. In 2014, the number of vacancies at ISM resulted in an extra, special, local (secondary-market) spot round. Nevertheless, ISM had 7 vacancies after this spot round. In 2015, ISM had 33 vacancies, and didn’t feel necessary to conduct a spot round.} are considered “less desirable”. The reduction clearly shows, and settles, the advantages of the joint system.

| Year | Participating institutes | Total seats | Vacancies | 2014 and prior institutes only |
|------|--------------------------|-------------|-----------|-------------------------------|
|      |                          |             |           | Vacancies                      | Reduction from 2014 |
| 2014 | 16 IITs + ISM            | 9,784       | 594       | 594                           |
| 2015 | 18 IITs + ISM            | 10,006      | 341       | 319                           | 46%                |
| 2016 | 23 IITs                  | 10,572      | 227       | 196                           | 67%                |
| 2017 | 23 IITs                  | 10,988      | 235       | 200                           | 66%                |

Table 8.1: The number of vacancies in the IITs over the years reduces substantially.

Note that, throughout the years, not only did new institutes get added in the system, but
the seat matrices of individual institutes also underwent modifications. Thus, the before-after comparison given here may underestimate, or cloud, the benefits from the joint allocation.

To address this issue, we conducted a counterfactual experiment to better assess how many vacancies were saved [4]. We simulated the earlier, separate allocation process on the same input as joint allocation for the years 2015-2017. In these experiments, the candidates would apply (virtually in the computer) only to the IITs first. Next, they apply only to the non-IIT programs they preferred more than their IIT allocations. As output, we checked how many candidates got a better preference than their IIT allocations, and presumed that these would represent the vacancies in IITs (since these candidates are likely to desert their IIT seats). We found that the joint process saved 371 (in 2015), 381 (in 2016) and 629 (in 2017) seats in the IITs.

As an aside, apart from saving vacancies, we found that many candidates obtained a better seat in the joint allocation scheme. In the earlier (separate) allocation process, a candidate A could occupy up to two seats: one in an IIT, and another in a non-IIT. Since the joint process allots her only one of those seats (the one preferred by her over the other), the second hoarded seat by A could now be offered to another candidate B, resulting in him getting a better preference. As a ripple effect, the seat vacated by B can now be offered to a third candidate C resulting in C getting a better preference as well. This cascading effect continues resulting in a number of benefited candidates, that is much greater than the number of vacancies! The numbers of benefited candidates were 1,866 (in 2015), 1,807 (in 2016), and 3,672 (in 2017).

8.2 Vacancies in the non-IITs

Since the non-IITs conducted their allocation after the IITs, we didn’t expect them to benefit from the joint process alone. We also couldn’t judge the impact to them from the counterfactual experiment. Despite being unable to draw a clear conclusion on the situation here, we report in Table 8.2 the progression of vacancies in these institutions. We note the reduction, and the downward trend in the reduction persists.

| Year | Participating institutes | Total seats | Vacancies | 2014 and prior institutes only |
|------|--------------------------|-------------|-----------|------------------------------|
|      | NITs | IITs | Other GFTIs |                 | Vacancies | Reduction from 2014 |
| 2014 | 30   | 12   | 16         | 21,285 | 5,596 | 5,596 | 12% |
| 2015 | 31   | 18   | 18         | 24,068 | 5,697 | 5,141 | 8% |
| 2016 | 31   | 20   | 18         | 24,323 | 4,901 | 4,379 | 22% |
| 2017 | 31   | 23   | 20         | 25,220 | 6,510 | 5,380 | 4% |

Table 8.2: Despite non-IITs admitting candidates after the IITs, vacancies in institutions reduce. Note the section on special round, though.

**Special Round** To mitigate the relatively high number of vacancies, the non-IITs conducted a centralized special round in 2015 and 2017. In 2015, in the special round, 5,354 fresh allotments were made, of which 2,683 candidates did not report, leading to a final vacancy count of 2,883 at the non-IITs. In 2017, 5,352 seats were allotted in the special round, of which 1,522 were rejected, leading to a final vacancy count of 2,680. Although the special round is quite effec-
Table 8.3: Withdrawals at the time of reporting for rounds 2 through 6 for 2016 and 2017. Withdrawals were not possible at Round 1 reporting, and they were not allowed at final round reporting (Round 6 in 2016 and Round 7 in 2017).

| Round | 2016  | 2017  |
|-------|-------|-------|
| 2     | 70    | 55    |
| 3     | 293   | 129   |
| 4     | 805   | 365   |
| 5     | 2,594 | 468   |
| 6     | N/A   | 4,168 |

Table 8.4: The number of seat rejections (when fresh allotments are made) for non-IIT allotments from 2015 to 2017. Note how over 70% of fresh allotments are rejected in later rounds.

| Round | 2015 (rejections/fresh) | 2016 (rejections/fresh) | 2017 (rejections/fresh) |
|-------|-------------------------|-------------------------|-------------------------|
| 1     | 6,585 / 23,956          | 5,591 / 24,245          | 5,920 / 25,114          |
| 2     | 3,571 / 6,954           | 2,373 / 5,977           | 2,695 / 6,262           |
| 3     | 2,617 / 3,655           | 1,330 / 2,487           | 1,612 / 2,802           |
| 4     | 2,166 / 2,624           | 1,010 / 1,698           | 1,180 / 1,905           |
| 5     | N/A                     | 1,272 / 1,762           | 1,164 / 1,562           |
| 6     | N/A                     | <No data> / 3,812       | 1,312 / 1,688           |
| 7     | N/A                     | N/A                     | <No data> / 5,259       |
Based on the above observations, we believe the vacancy problem can be mitigated by ensuring the following:

- The number of withdrawals is reduced.
- There is ample time after withdrawals for fresh allocations
- The number of rejections in the final round(s) is reduced

In [4], we suggest a few simple changes to the admissions process to obtain these improvements and hence drastically reduce vacancies. The interested reader is encouraged to go through them.

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3Note that seat cancellations (during document verification) are not counted towards rejections, but candidates with seat cancellations may be counted twice in fresh allotments (once at their first allotment, which got canceled and once again if they get allotted the second time). Also, withdrawals may be counted towards rejections only when they happen immediately after allotment (this happens very rarely in the data. The reason may be that the candidate reported first, and then withdrew in the same round). The number of seat cancellations and immediate withdrawals are generally small (less than a hundred).
Chapter 9

Conclusion

In this report we have described the details of a multi-run multi-round deferred acceptance (MRDA) algorithm used for allocating seats in 100 institutes with approximately 39000 seats and with over a million candidates. These institutes include the IITs (dictated by the Joint Admission Board (JAB)), and other centrally funded technical institutions (dictated by the Central Seat Allocation Board (CSAB)).

Prior to 2014, the allocations were decoupled leading to multiple problems. There were fairness issues (see the example in the introduction), and inefficiency issues such as seat vacancies, not to speak of logistic nightmare for high school graduates criss-crossing the country seeking admission towards the end of the admission process.

The method described in this report have been carried out by the Joint Seat Allocation Authority (JoSAA) for the last 4 years. It is provably fair and optimal in a formal sense. By providing a single window centralized process, the logistic difficulties of admission from a candidate perspective has reduced, even while keeping multiple merit lists of the varied institutes as the criteria for admission, and with no overbooking of seats allowed. It has led to a substantial reduction in seat vacancies (with further recommendations for adoption for JoSAA) as described here [4].

From a policy perspective, authorities are urged to bring the entire post high-school admission process (with multiple merit list criteria) under this one unified process.
Chapter 10

Appendix

10.1 Alternative algorithms to incorporate supernumerary seats for females

In this section, we present two simple algorithms which may appear to incorporate the rule of supernumerary seats for females correctly. However, each of them have one or more serious disadvantages.

10.1.1 Algorithm 1

This algorithm works as follows. Divide each virtual program into two separate virtual programs for non-females and females respectively. In the seat allocation process, non-females compete for non-female virtual programs and females compete for female virtual programs only. The capacities of these virtual programs may be fixed beforehand similar to our current algorithm presented in Chapter 7. The idea is that if the applicant pool looks like that of last year, we will end up with as many non-female candidates in each academic program as in 2017, whereas extra seats may be created for female candidates in a program as per the requirement.

Disadvantage of Algorithm 1:

This algorithm has a serious flaw — there may be potentially some female candidates who get denied a seat by this algorithm which they would have got otherwise by merit. This will happen, if for example, there are many top-ranked females beyond the capacity of the reserved sized female pool. This violation would defeat the whole objective — in the pursuit of providing a guarantee of at least 14% seats to females, this algorithm may deprive some female candidates of their right to compete for seats on the basis of merit. This serious problem in the algorithm was not merely a theoretical possibility because our simulations on the 2017 data revealed that the number of such female candidates was non-zero.

10.1.2 Algorithm 2

This algorithm works as follows. First we carry out the usual gender-neutral allocation like the previous years. We now freeze the allocation of non-females. Let there be $i$ females getting admitted to a virtual program $p$. If $i$ is less than 14% of the number of seats in $p$, we add
additional seats to program $p$ in an appropriate manner. Now we recompute the allocation for all females in these female-only programs.

**Disadvantage 1 of Algorithm 2:**
This algorithm may lead to merit violation as follows. In the process of satisfying the quota, there will be many programs where additional seats for females are created. As a result, when we carry out the allocation for females subsequent to the freeze, let’s say a female $x$ gets a more preferred program compared to the virtual program, say $p$, allocated to her in the pre-freeze gender-neutral allocation. Such a female will migrate to the more preferred program, and her earlier seat (in the gender-neutral category) gets allocated to some other female candidate $y$ with rank inferior to other candidates in the gender-neutral pool. In other words, now a female occupies a gender-neutral seat of $p$ with a rank which is worse than a male candidate to whom virtual program $p$ was denied. So the final allocation is unfair for non-females.

**Disadvantage 2 of algorithm 2:**
As mentioned in the beginning of Chapter 7, one constraint that has to be followed while incorporating the rule of supernumerary seats for females is that program capacities (seat matrix) have to be frozen prior to the joint seat allocation. This is because these capacities are publicly announced. Moreover they should be determined in a simple, transparent, and fair way. The allocation produced should not violate the pre-announced capacities. Unfortunately, Algorithm 2 violates this constraint since the capacities for each round will depend upon the outcome of the gender-neutral allocation for that round. In addition, there are non-trivial issues even in the generation of the seat matrices dynamically. We highlight them below through examples.

**Example 11.** What if there are only 5 SC seats a program and 3 of them are occupied by females in the gender-neutral allocation? Should we reserve the 3 seats for females? If so, it seems unjustified since the 3 females for whom we reserved these seats, most likely, might have gone to more preferred program after the female-only allocation that we carry out after the gender-neutral allocation.

**Example 12.** What if there are only 2 ST seats and both of them are occupied by males in the pre-freeze allocation? Should we create 0.28 supernumerary seats for females? If we do not create any seat, it may lead to less than 14% females violating the mandate of MHRD. If we create 1 seat for each such virtual program, we overshoot the 14% mark, violating the constraints of the institute. One could say that we may do it probabilistically: with probability 0.28 create 1 seat and 0 otherwise. But, the institutes will not be ready for the fluctuation it may create in the number of female candidates.

**Example 13.** What if nearly 40% seats of a program are occupied by female candidate. Going with Algorithm 2, we will freeze 60% seats for non-females and the remaining 40% seats will be filled by females. One may argue that we should continue to keep 40% seats for females in this program after the freeze, and before doing the dynamic allocation, since they were occupied by females on the basis of merit. But in this case, this argument is invalid, because the merit-worthy females who occupied these 40% seats migrate to the programmes of their higher choices in the IITs (for example), and these 40% seats will later (in the post-freeze phase) be occupied by females with much inferior rank. This begins to sound like 40% seat reservation for females which is against the mandate (at most 20% supernumerary seats for females).

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1There are some CSAB programs where it is indeed the case.
Note: The above examples are not hypothetical. These are real examples taken from the data of the joint seat allocations of the years 2015–2017.

Based on the above examples, it is easy to observe that there are two fundamental problems in the dynamic seat matrix generation carried out by Algorithm 2.

1. Algorithm 2 entails creation of the supernumerary seats at virtual program level. This leads to a fluctuation and hence uncertainty about the number of female candidates admitted. It may potentially lead to fewer than 14% females in an academic program (violating the mandate of MHRD) or much more females (infrastructural problems by institutes). The reader may verify that our algorithm in Chapter 7 does not have these two shortcomings.

2. Handling of the programs where females are much more than 20% is unjustified. As in the example, we may end up reserving a large number (e.g., 40%) of seats for females. Compared to this, our algorithm in Chapter 7 handles it in a much more rational way: assigns 14% - 20% seats for female-only and the remaining to be Gender-neutral. It still allows 40% females if they come by merit, but not otherwise.

10.2 Summary of activities at reporting centers

In this section, we provide a summary of the activities that take place at reporting centers during a round. There are numerous activities carried out at a reporting center. However, we provide here the details of only those activities during a round that are essential from the perspective of seat allocation to be carried out for the next round. First we mention the tables that get updated based on these activities.

1. Allotment table.
   For each candidate who is allotted a seat in a round, the allotment table provides the complete information of the seat allocated to her. This table is one of the output files of the seat allocation algorithm (see Section 10.5). However, a candidate who is allocated a seat might not report at the reporting center. Even if she reports, the seat may get cancelled during document verification. Or the candidate willingly surrenders the seat in the same or later round, and thus withdraws from the joint seat allocation. This entire information is captured in two fields, namely, “RStatus” and “Withdraw”. These two fields are appended to the allotment table of the current round and are used for the seat allocation of the next round.

2. Candidate table.
   Candidate table is one of the input files of the seat allocation algorithm (see Section 10.5). During document verification, if the credentials of a candidate change, the candidate table is updated accordingly. To mark that the credentials of a candidate change, the value of “CatChange” field in this table is updated accordingly.

3. Preference list (Choice table).
   The preference list of a candidate may change during document verification. For example, if a candidate is found to be color-blind and the candidate had mentioned Mining program
in the preference list, then the validity field of mining program in the preference list is marked N.

Now we provide a summary of the activities at the reporting centers followed by the way the tables mentioned above get updated based on these activities.

Once a candidate gets allocated a seat for the first time, the candidate has to report at the appropriate reporting center for document verification and seat confirmation. For this purpose, “RStatus” field of each such candidate is initialized as NR (acronym for Not Reported) and “Withdraw” field is initialized as N (acronym for Not) in the beginning of the round. Based on the activities at the reporting center, these fields are updated appropriately as described below.

If the candidate does not report during the round, the RStatus remains NR, and the candidate will not be considered for seat allocation in future rounds. If the candidate reports at the reporting center, then the following are the possible outcomes.

1. If the candidate is able to produce all the relevant documents and the documents are verified to be authentic, her seat gets confirmed. RStatus become RP (acronym for Reported). If the candidate fails to produce some document or the documents produced have any discrepancy, the candidate’s credentials have to be changed. For example, the candidate may be claiming to be OBC-NCL, but fails to produce valid OBC-NCL certificate at the reporting center. In this case, the candidate’s category is changed to GENERAL. Another example is a candidate who gets Mining program but is found to be color-blind. There are many other examples that results in change in credentials. The change in credentials may lead to the following two possible outcomes.

The change in credentials may lead to cancellation of her seat. For example, if a candidate got seat in OBC-NCL virtual program but fails to produce valid OBC-NCL certificate, then her seat will get cancelled. Another case is a candidate who gets Mining program but is found to be color-blind. There are many other cases as well. In each such case that leads to the cancellation of a seat, the RStatus of the candidate is set to RC (acronym for Reported and seat Cancelled). The CatChange field of the candidate in the candidate table will be set to 1 or 4. The candidate will be considered for seat allocation in future rounds based on the revised credentials.

It is also possible that the credentials of the candidate change but the seat is not cancelled. For example, if an OBC-NCL candidate gets a seat from OPEN category but fails to produce valid OBC-NCL certificate at the reporting center. In such case, CatChange field of the candidate is set to 3. The RStatus of the candidate will be set to RP. The candidate will be considered for seat allocation in future rounds with revised credentials (the birth category will be GEN in this case).

Note that a change in credentials may also result in making some choices (programs) in the preference list of the candidate invalid. For example, if the board marks of the candidate fail to satisfy the criteria of minimum board marks for admission into IITs (likewise CSAB), all IIT (likewise CSAB) programs in her preference list will become invalid. Another example is a candidate who opted for Mining program but is found to be color-blind. In this case, the Mining program will become invalid in the preference list of the candidate.
2. During the verification of the documents, the candidate may be found to be ineligible for joint seat allocation. In such a case, the seat of the candidate is canceled and the candidate is removed from the list of eligible candidates (Candidate table) for future rounds. This candidate will not be considered for seat allocation in future rounds.

At the reporting center, if the seat of the candidate gets confirmed, the candidate may also exercise her options of Freeze/Float/Slide. Accordingly the “Decision” field of the candidate in the candidate table is updated to FR/FL/SL. If the seat of the candidate gets canceled but the candidate is still eligible for seat allocation in future rounds with revised credentials, the Decision field continues to remain Float. If a candidate does not report at the reporting center, Decision field is set to RJ.

Note that there may be candidates in the current round of allotment who might have got a seat in previous rounds which they accepted as well. If the seat remains unchanged in the current round, then RStatus of such a candidate is set to RT (acronym for seat Retained). These candidates are not required to report at the reporting center again. But if the seat gets upgraded in the current round, then there are two possibilities. If the previous seat was in some CSAB institute and the new seat is in some IIT (or vice versa), then the candidate must report at the reporting center of some IIT (likewise CSAB institute for the reverse case). The RStatus of such candidate is set to DR (acronym for Dual Reporting). Processing of such a candidate is identical to the candidates with RStatus=NR as described above. If the upgraded seat is still from the same pool of institutes (IITs or CSAB) as that of the previous seat, then the candidate is not required to report at the reporting center again. RStatus is set to RU (acronym for Retained and Upgraded) for such a candidate. Once a candidate gets a seat in a CSAB institute (likewise IIT), and her seat gets confirmed upon reporting at some reporting center of CSAB institutes (likewise IIT), she will not have to report again at any reporting center of CSAB institutes (likewise IIT). In other words, in normal circumstances, a candidate may be upgraded multiple times.

In addition to the above activities at reporting center, the candidate may also visit reporting center for other activities. A candidate has to approach the reporting center if she decides, ever in future rounds, to exercise Freeze/Float/Slide. A candidate, who got a seat in some round, may also wish to surrender her seat and withdraw from joint seat allocation for that year. For this purpose, she has to report at the reporting center after initializing the withdraw process through his/her JoSAA login. The Withdraw field of such candidate in the Allotment file is set to Y after all the formalities of withdraw are completed at the reporting center.

Now we describe how the input for 2nd (or subsequent) round is computed based on the activities at reporting center described above.

1. Updating Candidate table.

The credentials of a candidate may change during the document verification at the reporting center during a round. The credentials will be updated accordingly in the candidate table for the next round. The CatChange field is updated accordingly based on the type of credentials that got changed. The “Decision” field is also changed based on the option (Freeze or Float or Slide) chosen by the candidate at the reporting center. Here we would like to state some more information about Decision field. Once a candidate reports at the reporting center, the following are the possibilities of the change in this field.
(a) Her seat is confirmed. In that case, The Decision field may be set to Freeze or Float or Slide based on the option given by the candidate at the reporting center.

(b) Her seat is cancelled but she will still be considered for seat allocation in future rounds. Decision field will be set to Float for such candidates.

(c) She does not report at the reporting center. In this case, Decision field is set to RJ.

Note that the candidates who become ineligible for seat allocation after document verification are removed from the candidate table in subsequent rounds. The converse may also happen (though it is rare). The board marks of a candidate may increase after re-evaluation and a candidate, who was ineligible previously, may potentially become eligible for seat allocation in CSAB institutes and/or IITs (note that these two pools may have different eligibility criteria of board marks).

2. Augmenting the allotment table.
   Based on the reporting center activities as described above, RStatus and Withdraw fields of the candidates is updated as described above. These two fields are appended to the allotment table of the current round. This augmented file will be used for computing the seat allocation for the next round (for computing Min-Cutoff for each virtual program). It is therefore given as input for the next round and called ‘allotment table of the previous round’.

3. Updating the preference list (Choice table).
   Based on the credential changes, the preference list of the candidate will be updated. In particular, some choices may become invalid after document verification as described above. The “Validity” field of such choices is marked N.

Although we provided complete details of the reporting center activities above, a programmer needs to focus on the following specific points while writing the code for seat allocation.

1. In order to determine if the seat of the candidate is cancelled, just check RStatus field and Withdraw field from the allotment table of the previous round. If RStatus=NR/DR/RC, or Withdraw=Y, the seat of the candidate is cancelled.

2. In order to determine the current preference list, the “Decision” field is required and the preference list needs to be pruned if needed. Also the validity field of programs in the preference list needs to be taken into account while reading - If validity field of a program is N, that program must be skipped while creating virtual preference list of the candidate.

3. For the first 3 years of the joint seat allocation, CatChange field in Candidate table used to be considered for seat allocation computation in each round. But after a change in a business rule in 2018 (refer to Section 10.6), this field can be safely ignored as far as seat allocation in any round is concerned.

### 10.3 Survey Questions

Candidates who wish to surrender their seat and withdraw from the joint seat allocation should be asked to fill out a survey before their fees are refunded. This survey should be analysed at
the end of the joint seat allocation every year so that the efficiency of the joint seat allocation can be improved in the future years. Here is a possible mini-survey design:

This survey is intended to obtain a detailed understanding of the performance of JoSAA 20xx, and possibly suggest areas for potential further improvements in efficiency of seat allocation. Complete privacy of your data is guaranteed. There will be no penalties of any kind based on information entered here. We appreciate your help in providing us this vital information.

Why did you choose to not take-up your allocation of program ??? in round ??? of JoSAA 20xx?

Please select the appropriate option:

- Want to write JEE again.
- Admitted to other Institute
  - (i) Institute name ________ (ii) Date of admission notification ________
- Other. (i) Please specify ________ (ii) Date of decision ________ (select on a calendar)

Thank you for your assistance!

10.4 Validation Modules

An important challenge is to verify whether the output of the DA algorithm for a large test case (nearly 13 lakh candidates) satisfies various business rules. Validation modules provide effective ways to achieve this goal. Each validation module will take the input and output files of the DA algorithm for a round and verify whether the output is indeed correct for the given input. There are two types of validation modules.

10.4.1 Candidate specific validation modules

There are 6 validation modules required to ensure that allotment meets the business rules for the candidates.

Fairness

Suppose a candidate $c$ is denied a virtual program $p$. Then the rank of each candidate getting $p$ must be superior to the rank of $c$. This module can be implemented efficiently with the help of the closing rank as follows. The closing rank of each of the virtual programs that rejected $c$ must be better than the rank of $c$. Note that this module seamlessly takes care of the current implementation of the supernumerary seats for females.

Quota Eligibility

NIT program has home state (HS) and other state (OS) quota. Similarly for other GFTIs, each program has home state (HS) and all India (AI) quota. Quota eligibility requires the following condition to be guaranteed for HS quota (similarly for OS and AI). A candidate can be allotted a seat from HS quota of a program only if she is eligible for the HS quota of that program; conversely, if the candidate is not eligible for the HS quota, she should not be awarded the seat from HS quota.
Category Eligibility

The aim of this module is to verify that a candidate must be assigned seat from the category for which she is eligible. For example, a SC candidate who does not appear in CRL cannot be assigned a seat from any OPEN virtual program. In a similar manner, a GEN candidate cannot be assigned a seat from an SC virtual program.

Candidate willingness

After a given round, the candidates who are allotted programs may opt for any of the following options: Freeze, Float, Slide, or Reject. These options must be respected while allocating programs to them in the following rounds.

Seat guarantee in later rounds (Min-Cutoff benefit)

Each eligible candidate will get Min-Cutoff benefit. That is, if $c$ is a candidate applying to a virtual program $p$. If rank of $c$ is better than the Min-Cutoff($p$), then $c$ will surely be given a seat in $p$ irrespective of whether or not there is any vacancy in $p$.

Fairness guarantee for non-female candidates

If the number of non-female candidates in a Gender-neutral virtual program $p$ turns out to be less than the seat capacity of $p$, then either there is a vacancy in $p$ or there is at least one female candidate getting a seat in $p$.

Fairness guarantee for female candidates

If a male candidate $c$ gets a seat in a virtual program $p$, then every female candidate eligible for the virtual program $p$, must be given a seat in $p$ if her rank is same or better than that of $c$.

10.4.2 Program specific validation modules

There are two broad validation modules to verify whether the allotment meets the business rules of the programs.

Validating de-reservation

During multiple runs of DA in a round, the capacity of a virtual program may change due to de-reservation. Thus within a round, the seat matrix may change. However, the capacities of the sum of all virtual programs must remain unchanged. The checks we can do here are:

- Sum of capacities of all virtual programs is the same before and after de-reservation. In fact, the following equation should hold for each virtual program $p$

  \[ \text{NewCap} = \text{InitCap} + \text{No. of seats de-reserved to } p - \text{No. of seats de-reserved from } p \]

- A virtual program from which de-reservation happened cannot have any supernumerary seat.
• A virtual program from which de-reservation happened must not be denied to any candidate eligible for that virtual program. That is, there should be no eligible candidate who applied to this program and didn’t get it.

Validating the cause of supernumerary seats

The number of candidates getting a virtual program may be more than the capacity of the virtual program. The surplus candidates are given supernumerary seats. The cause of supernumerary seats may be any one of following:

• Multiple candidates at closing rank (EQ)
• Min-Cutoff criteria (MC)
• Foreign nationals (FR)
• Foreign nationals with multiple candidates at closing rank (FE)
• Foreign nationals getting seat by Min-Cutoff criteria (FM)
• DS candidate (DS)
• DS candidates with multiple candidates at closing rank (DE)
• DS candidates getting seat by Min-Cutoff criteria (DM)

In order to verify the cause of supernumerary seats, additional information has been provided in the allotment table. The validation module for supernumerary seats should use this information.

In order to assist the people engaged in validating/testing the output of the seat allocation software, the allotment table will have 2 columns (Flag, SupNumReason). These columns will be used to compute Min-Cutoff of a virtual program for the next round, provide and verify the reason for the creation of supernumerary seats in a virtual program. In addition to the augmented allotment table, the following table will also be output by the DA implementation.

Program Statistics

For each virtual program, the following information will be mentioned.

• Opening rank of the virtual program.
• Closing rank of the virtual program.
• MinCutOff of the virtual program.
• Total candidates allotted to the virtual program.
• Initial and final capacity of the virtual program.
• The number of seats that got dereserved to and from the virtual program.
• The number of supernumerary seats created in the virtual program.

These are two different columns DereserveTo and DereserveFrom.
Allotment comparing module

In order to compare two allotments (produced by two different implementations), a module that highlights the candidates whose allotment differs in the two allocations may prove to be very useful. This module will help testing/validating team and may help fixing of a bug, if any. Such a module was a part of the IITK implementation of the DA algorithm in 2015 and 2016, and it proved to be very helpful.

10.5 Implementation Details of MRDA

In this section we present the implementation details of the algorithm. In particular, we elaborate on the input, output, and the interface of the DA algorithm along with its interaction with the reporting center during any round.

10.5.1 Algorithm: interface and interactions

Seat allocations happen in multiple stages (or rounds). The key difference between the first round and subsequent rounds is that some candidates have seats that the Joint Seat Allocation Authority (JoSAA) agrees to a guarantee - seats offered in prior rounds (e.g. “Freeze”) will continue to be available. Having a single implementation of the DA algorithm (with updated inputs) that works for every round is better than having multiple implementations. We have to validate only one implementation. We call such an implementation a “generic” implementation. Figure 10.1 shows the interface (input/output) of the generic DA algorithm.

We provide below a summary of four tables that will serve as input to the generic implementation of DA algorithm, and also two output tables.

- **Seat_Matrix:** The table stores the list of programmes of various institutes that participate in the joint seat allocation along with their capacities. Seat matrix will remain the same for each round. (However, internally, during multiple runs, this matrix may change due to de-reservation.) Seat matrix is obtained from the institutes.

- **Choice list of Candidates:** This table correspond to the preference list mentioned in our algorithm. This table stores the choices (programs) of each candidate. For each candidate the choices will appear in this table in the decreasing order of her preference. The table for the (N+1)th round is defined by the table for the (N)th round, the candidate willingness option (freeze/float/slide/reject). The validity field of one ore more program may also be updated based on the activities at the reporting center. The willingness information is not a part of this table, but is available in the 63rd column of the Eligible_Candidate_JoSAA table mentioned below. The initial table is obtained after JEE Mains Rank List and JEE Advanced Rank List are declared. N is indexed starting from 1.

- **Eligible_Candidate_JoSAA** (Candidate table): This table stores personal and other eligibility information of candidates. The information is collected at the time of the registration for the exam. For JEE Mains, this information can be quite dated, being collected almost six months in advance. The information in this table is vulnerable,
because, for example, the OBC\_NCL status of candidates can change, possibly due to change in income. This table will be provided externally at the beginning of every round. For any round, the table will consist of all those eligible candidates who have at least one valid choice in their respective choice lists. For round (N+1), N ≥ 1, this table will have meaningful information in the following fields.

- CredentialChange: This field will take value from \{1,2,3,4\}. For the 1st round, the value will be 2.
- Decision: This field will be one of Freeze/Float/Slide/Reject/Withdraw depending upon the option exercised by the candidate after a seat is allocated. This field will be used for computing the choice list of the candidate for the (N+1)th round.

**Min-Cutoff.**
This table will store min-cut-off for each virtual programme. For the first round, it will be set to 0 for all virtual programmes. Min-Cutoff for a virtual programme prior to the execution of round (N+1) will be computed using the allotment table of the (N)th round and the Decision field (column 63) of the Eligible\_Candidate\_JoSAA file mentioned above.

The output of the algorithm for each round will be the following two tables.
• **Allotment**
  This table will store the details of the program, if any, allotted to each candidate. The allotment table has two significant columns for purposes of multiround DA. Details appear below.

• **Program Statistics**
  This table will store the details of the program statistics (opening rank, closing rank, supernumerary information, and de-reservation information).

Please refer to Figure 10.1 for the interface of the generic DA algorithm and refer to Figure 10.2 for various activities that take place during any round.

Figure 10.2 depicts the execution of the algorithm and activities that take place during \((i + 1)\)th round.

![Figure 10.2: The activities during \((i + 1)\)th round](image)
10.5.2 Input format

The complete details of the three input tables are given below.

Seat Matrix

| S. No. | Column Name   | Type    | Description                  |
|--------|---------------|---------|------------------------------|
| 1.     | Quota         | char(2) | AI/HS/OS                     |
| 2.     | InstCd        | char(3) | Institute Code               |
| 3.     | BrCd          | char(4) | Branch Code                  |
| 4.     | GenderPool    | char(6) | Gender pool with two possibilities: Neutral or Female |
| 5.     | OP            | int     | Open Seats                   |
| 6.     | OP_PwD        | int     | Open-PwD Seats               |
| 7.     | SC            | int     | SC Seats                     |
| 8.     | SC_PwD        | int     | SC-PwD Seats                 |
| 9.     | ST            | int     | ST Seats                     |
| 10.    | ST_PwD        | int     | ST-PwD Seats                 |
| 11.    | OBC_NCL       | int     | OBC-NCL Seats                |
| 12.    | OBC_NCL_PwD   | int     | OBC-NCL-PwD Seats            |
| 13.    | Total         | int     | Total Seats                  |
| 14.    | StCd1         | char(2) | State code of Eligibility    |
| 15.    | StCd2         | char(2) | State code of Eligibility    |
| 16.    | StCd3         | char(2) | State code of Eligibility    |
| 17.    | StCd4         | char(2) | State code of Eligibility    |

Choice list of a candidate

| S. No. | Column Name | Type    | Description                      | Remarks                                           |
|--------|-------------|---------|----------------------------------|--------------------------------------------------|
| 1.     | RollNo      | char(8) | JEE (Main) Roll number          |                                                  |
| 2.     | OptNo       | int     | Option No                       |                                                  |
| 3.     | InstCd      | char(3) | Institute Code                  |                                                  |
| 4.     | BrCd        | char(4) | Branch Code                     |                                                  |
| 5.     | Validity    | char(1) | NULL (default)- if choice is valid N - Choice is not valid | this field will be updated at the time of Document verification |

Candidate Table
| S. No. | Column name           | Type and Length | Description                        | Remark     |
|-------|-----------------------|-----------------|------------------------------------|------------|
| 1.    | RollNo                | char(8)         | JEE(Main) Roll Number              |            |
| 2.    | AppNo                 | char(8)         | JEE(Main) Application No           |            |
| 3.    | NAME                  | varchar(46)     | Candidate Name                     |            |
| 4.    | MNAME                 | varchar(46)     | Mother Name                        |            |
| 5.    | FNAME                 | varchar(46)     | Father Name                        |            |
| 6.    | GName                 | varchar(46)     | Guardian Name                      |            |
| 7.    | SCode                 | char(2)         | State Code of Eligibility          |            |
| 8.    | Gender                | char(1)         | 1-Male, 2-Female, 3-Transgender    |            |
| 9.    | DOB                   | char(10)        | Date of Birth (DD/MM/YYYY)         |            |
| 10.   | CAT                   | char(2)         | GN/SC/ST/BC                        |            |
| 11.   | PwD                   | char(1)         | 1-YES, 2-NO                        |            |
| 12.   | Nationality           | char(1)         | 1-Indian, 2-OCI, 3-PIO, 4-Foreign  |            |
|       |                       |                 | (Other than OCI, PIO)              |            |
| 13.   | AI_Eng_CRL_Rank       | float           | JEE(Main) All India Eng CRL Rank   |            |
| 14.   | AI_Eng_OBC_NCL_Rank   | float           | JEE(Main) All India Eng OBC-NCL Rank|            |
| 15.   | AI_Eng_SC_Rank        | float           | JEE(Main) All India Eng SC Rank    |            |
| 16.   | AI_Eng_ST_Rank        | float           | JEE(Main) All India Eng ST Rank    |            |
| 17.   | AI_Eng_CRL_PD_Rank    | float           | JEE(Main) All India Eng CRL-PwD Rank|            |
| 18.   | AI_Eng_OBC_NCL_PD_Rank| float           | JEE(Main) All India Eng OBC-PwD Rank|            |
| 19.   | AI_Eng_SC_PD_Rank     | float           | JEE(Main) All India Eng SC-PwD Rank|            |
| 20.   | AI_Eng_ST_PD_Rank     | float           | JEE(Main) All India Eng ST-PwD Rank|            |
| S. No. | Column name          | Type and Length | Description                                                                 | Remark                                                                 |
|-------|----------------------|-----------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------|
| 21.   | Eng_Rem_Symb         | char(1)         | JEE (Main) - BE/B.Tech Eligibility Remark symbol                           | '*' - Eligible under CRL                                              |
|       |                      |                 | '=' - Eligible for OBC-NCL seats only                                       | '+' - Eligible for SC/ST/PwD seats only                              |
|       |                      |                 | '$' - Eligible for OBC-NCL-PwD seat only                                    | '%' - Eligible for GEN-PwD seat only                                  |
|       |                      |                 | 'N' - Non Eligible for Seat Allocation                                      |                                                                        |
| 22.   | AI_Arc_CRL_Rank      | float           | JEE(Main) All India Arc CRL Rank                                             |                                                                        |
| 23.   | AI_Arc_OBC_NCL_Rank  | float           | JEE(Main) All India Arc OBC-NCL Rank                                         |                                                                        |
| 24.   | AI_Arc_SC_Rank       | float           | JEE(Main) All India Arc SC Rank                                              |                                                                        |
| 25.   | AI_Arc_ST_Rank       | float           | JEE(Main) All India Arc ST Rank                                              |                                                                        |
| 26.   | AI_Arc_CRL_PD_Rank   | float           | JEE(Main) All India Arc CRL-PwD Rank                                         |                                                                        |
| 27.   | AI_Arc_OBC_NCL_PD_Rank| float         | JEE(Main) All India Arc OBC-PwD Rank                                         |                                                                        |
| 28.   | AI_Arc_SC_PD_Rank    | float           | JEE(Main) All India Arc SC-PwD Rank                                          |                                                                        |
| 29.   | AI_Arc_ST_PD_Rank    | float           | JEE(Main) All India Arc ST-PwD Rank                                          |                                                                        |
| S. No. | Column name               | Type and Length | Description                                      | Remark                                |
|--------|---------------------------|-----------------|--------------------------------------------------|---------------------------------------|
| 30.    | Arc_Rem_Symb              | char(1)         | JEE (Main) - B Arch/B.Planning Eligibility       | Remark symbol                        |
|        |                           |                 |                                                   | ‘*’ - Eligible under CRL              |
|        |                           |                 |                                                   | ‘:=’ - Eligible for OBC-NCL seats only|
|        |                           |                 |                                                   | ‘+’ - Eligible for SC/ST/PwD seats only|
|        |                           |                 |                                                   | ‘$’ - Eligible for OBC-NCL-PwD seat only|
|        |                           |                 |                                                   | ‘%’ - Eligible for GEN-PwD seat only   |
|        |                           |                 |                                                   | ‘N’ - Non Eligible for Seat Allocation |
| 31.    | Adv_RollNo                | char(7)         | JEE(Advanced) Roll Number                        |                                       |
| 32.    | Adv_RegNo                 | char(10)        | JEE(Advanced) Registration Number                |                                       |
| 33.    | Adv_CRL_Rank              | float           | JEE(Advanced) Common Rank List                   |                                       |
| 34.    | Adv_OBC_NCL_Rank          | float           | JEE(Advanced) OBC-NCL Rank                        |                                       |
| 35.    | Adv_SC_Rank               | float           | JEE(Advanced) SC Rank                            |                                       |
| 36.    | Adv_ST_Rank               | float           | JEE(Advanced) ST Rank                            |                                       |
| 37.    | Adv_CRL_PD_Rank           | float           | JEE(Advanced) CRL-PwD Rank                        |                                       |
| 38.    | Adv_OBC_NCL_PD_Rank       | float           | JEE(Advanced) OBC-NCL-PwD Rank                    |                                       |
| 39.    | Adv_SC_PD_Rank            | float           | JEE(Advanced) SC-PwD Rank                         |                                       |
| 40.    | Adv_ST_PD_Rank            | float           | JEE(Advanced) ST-PwD Rank                         |                                       |
| S. No. | Column name           | Type and Length | Description                                                                 | Remark                                                                 |
|-------|-----------------------|-----------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------|
| 41.   | Adv_Rem_Symb          | char (1)        | JEE (Advanced) - Eligibility Remark symbol                                 |                                                                       |
|       |                       |                 | ‘*’ - Eligible under CRL                                                  |                                                                       |
|       |                       |                 | ‘=’ - Eligible for OBC-NCL seats only                                    |                                                                       |
|       |                       |                 | ‘+’ - Eligible for SC/ST/PwD seats only                                  |                                                                       |
|       |                       |                 | ‘$’ - Eligible for OBC-NCL-PwD seat only                                 |                                                                       |
|       |                       |                 | ‘%’ - Eligible for GEN-PwD seat only                                      |                                                                       |
|       |                       |                 | ‘P’ - Eligible for Preparatory seat                                       |                                                                       |
|       |                       |                 | ‘N’ - Non Eligible for Seat Allocation                                    |                                                                       |
| 42.   | Adv_IsPrep            | char(1)         | Is eligible for Preparatory (1-Yes, 2-No)                                 |                                                                       |
| 43.   | Adv_Prep_SC_Rank      | float           | Preparatory Rank for SC candidates                                        |                                                                       |
| 44.   | Adv_Prep_ST_Rank      | float           | Preparatory Rank for ST candidates                                        |                                                                       |
| 45.   | Adv_Prep_CRL_PD_Rank  | float           | Preparatory Rank for all PwD candidates                                    |                                                                       |
| 46.   | Adv_Prep_OBC-NCL_PD_Rank | float         | Preparatory Rank for OBC-NCL PwD candidates                               |                                                                       |
| 47.   | Adv_Prep_SC_PD_Rank   | float           | Preparatory Rank for SC-PwD candidates                                    |                                                                       |
| 48.   | Adv_Prep_ST_PD_Rank   | float           | Preparatory Rank for ST-PwD candidates                                    |                                                                       |
| 49.   | Adv_AAT_Status        | char(1)         | 1-Qualified, 2-Not Qualified                                               |                                                                       |
| 50.   | Adv_DS                | char(1)         | DS Status (1-Yes, 2-No)                                                    |                                                                       |
| 51.   | Adv_colour_blind      | char(1)         | 1-Yes, 2-No                                                                |                                                                       |
| 52.   | Adv_OneEyedVision     | char(1)         | 1-Yes, 2-No                                                                |                                                                       |
| 53.   | Eng_Top_20            | char(1)         | NULL                                                                       |                                                                       |
| 54.   | Arc_Top_20            | char(1)         | NULL                                                                       |                                                                       |
| 55.   | Adv_Top_20            | char(1)         | NULL                                                                       |                                                                       |
| S. No. | Column name         | Type and Length | Description                           | Remark |
|-------|---------------------|-----------------|---------------------------------------|--------|
| 56.   | Board_Mark_Eng      | float           | NULL                                 |        |
| 57.   | Board_Mark_Arc      | float           | NULL                                 |        |
| 58.   | Board_Mark_Adv      | float           | NULL                                 |        |
| 59.   | Board_RollNo        | varchar         | Board Roll No                        |        |
| 60.   | Board_Year_Passing  | varchar         | Year of passing of class 12th or equivalent |        |
| 61.   | Board_Name          | varchar         | School Board Name                    |        |
| 62.   | CatChange**         | char(1)         | 1,2,3,4 (Default value is 2)         |        |
| 63.   | Decision            | char(2)         | FR: Freeze                           |        |
|       |                     |                 | FL: float                            |        |
|       |                     |                 | SL: Slide                            |        |
|       |                     |                 | RJ: Reject                           |        |

**Credential Change Description**

The CatChange field flags the change in credentials of a candidate. The value of this field will be one of 1, 2, 3, or 4. The following is the description of different values of this field.

1: If the credential changes are among the following:
   1. Nationality change, 2. Home state change, 3. Birth category change
   4. DS status change, 5. PwD status change, 6. Gender change
   In this case, his/her seat is cancelled.

2: This is the default value. It means no change in candidate credentials.

3: If his/her credentials changed but seat was not cancelled. Example: an OBC_NCL candidate got a seat from GEN category but his/her OBC_NCL certificate is found to be invalid at the reporting center.

4: If the credential changes are among the following:
   1. OneEyedVision status change, 2. ColorBlindness status change
   In this case, the seat of the candidate is cancelled.

**10.5.3 Output format**

Allotment Table
| S. No. | Column name | Type and Length | Description | Remark |
|-------|-------------|-----------------|-------------|--------|
| 1.    | RoundNo     | int             | Round No    |        |
| 2.    | RollNo      | char(8)         | JEE(Main) Roll Number |        |
| 3.    | Birth_Cat   | char(2)         | Candidate birth category |        |
| 4.    | Optno       | int             | Option No   |        |
| 5.    | InstCd      | char (3)        | Institute Code |        |
| 6.    | BrCd        | char(4)         | Branch Code |        |
| 7.    | Rank        | float           | Rank used for seat allocation |        |
| 8.    | AllottedCat | char(4)         | Allotted Category. 8 possibilities: OPNO, OPPH, BCNO, BCPH, SCNO, SCPH, STNO, STPH | First two characters correspond to the birth category and the second two correspond to the PwD status of the candidate for which this program is reserved |
| 9.    | AllottedQuota | char(2)   | Allotted Quota (AI/HS/OS/AP/GO) |        |
| 10.   | GenderPool  | char(6)         | Allotted gender pool with two possibilities: Neutral or Female |        |
| 11.   | Flag        | char(1)         | Four possibilities: N: Normal, D: DS, F: Foreign, P: Preparatory (Default: N) | D: DS seat is given to the candidate. A DS candidate can also receive a "N" normal seat. |
| 12.   | SupNumReason | char(2)    | NA- Not Applicable (Default) EQ- Closing rank equality MC- Min Cutoff FR- Foreign national FE- Foreign national with closing rank equality FM- Foreign national with Min Cutoff DS- DS consideration DE- DS with closing rank equality DM- DS with Min Cutoff | If 5 candidates are at the same closing rank, any 4 of them can be marked as EQ. Similarly, if 5 supernumerary seats are created due to min-cut-off, any 5 candidates clearing min-cut-off and whose category didn’t change can be marked as MC |
| 13.   | Withdraw    | char(1)         | Two possibilities: Y/N | To determine if candidate has withdrawn |
| 14.   | RStatus     | char(2)         | Six possibilities: NR,DR,RC,RP,RT,RU | To determine the reporting status of candidate |

Note: Allotment table output by the seat allocation algorithm has only the first 12 fields. The last 2 fields, namely “RStatus” and “Withdraw” are appended to the allotment table based on the activities at reporting center. The resulting table, called allotment table of the previous round, is used for the seat allocation of the next round.
### Program Statistics

| S. No. | Column name | Type and Length | Description | Remark |
|--------|-------------|-----------------|-------------|--------|
| 1.     | Quota       | char(2)         | Quota       | HS/OS/Al |
| 2.     | InstCd      | char(3)         | Institute Code | |
| 3.     | BrCd        | char(4)         | Branch Code | |
| 4.     | VCategory   | char(4)         | Category of virtual programme. One among OPNO, OPPH, BCNO, BCPH, SCNO, SCPH, STNO, STPH, and DSNO | DSNO if the programme is DS virtual programme. BrCd should be 0000 then |
| 5.     | GenderPool  | char(6)         | Gender pool: Neutral or Female | |
| 6.     | OpeningRank | float           | Opening Rank | |
| 7.     | ClosingRank | float           | Closing Rank | |
| 8.     | MinCutOff   | float           | The min cut off used for allotment in the current round. | This field is computed in the beginning of the current round using the output of the previous round. |
| 9.     | TotalAllotted | int             | The number of candidates to whom the programme is allotted | |
| 10.    | InitCap     | int             | Initial capacity | |
| 11.    | NewCap      | int             | Capacity after de-reservation | Includes non-supernumerary seats given to DS candidates |
| 12.    | DeReserveFrom | int             | Number of seats that got de-reserved from this virtual programme | |
| 13.    | DeReserveTo | int             | Number of seats that got de-reserved to this virtual programme | |
| 14.    | SuperNum    | int             | Number of supernumerary seats created in this virtual programme | Includes supernumerary seats created due to all possible reasons. |

### 10.6 Changes in Business rules since 2015

We now state the changes in the business rules that have occurred in the last 4 years of joint seat allocation. Each of these changes were duly approved in respective JoSAA meetings after long deliberation, and in some cases justified through scientific analysis of data of one or more years of the joint seat allocation.

- Preferential allocation of seats for DS candidates.
  
  In 2015, the seats for DS candidates were allotted in preferential manner, and these seats had to be from the Open category. The reader may refer to Technical Report [3] for the algorithm to handle DS candidates during Joint Seat Allocation 2015. We have reproduced this algorithm in Appendix [10.7]. However, from 2016 onwards, DS candidates are given seats in supernumerary fashion.

- Influence of board marks on merit list of CSAB institutes.
In 2015 and 2016, board marks of a candidate were considered in computing the final rank of a candidate in the merit list used for CSAB institutes. But from 2017 onwards, the board marks are used only as qualifying marks. The merit list for admission into CSAB institutes is based only on the performance in the JEE main exam.

- Provision to withdraw from joint seat allocation.
  After accepting a JoSAA seat, a candidate may get a better (from the perspective of the candidate) program in some other institute outside JoSAA. Such a candidate should be allowed to surrender her current seat and withdraw from joint seat allocation. But, there was no provision to withdraw in 2015. Without the provision of withdraw, the seat vacated by the candidate will never be filled. However, from 2016 onwards, option to withdraw was provided to the candidates. Each candidate who accepts a seat was allowed to withdraw till the end of the 6th round (total number of rounds are 7).

- Penalty of CatChange=1 candidates.
  During document verification at the reporting center, certain changes in the credentials may result in setting CatChange field to 1. Not only the seat of such a candidate gets canceled, as a penalty the candidate may compete only for vacant seats in subsequent rounds. Such candidate were deprived from Min-Cutoff benefit. The reader may refer to the Technical Report of 2015 for the details of the algorithm to implement this business rule. The objective underlying this business rule was to avoid creation of supernumerary seats. However, it was found through simulations on the data of 2017 that the number of supernumerary seats avoided by this rule was less than 10. In addition, it was felt that the penalty imposed by this rule is too harsh for a candidate. So this rule was changed in 2018. According to the new rule, if a candidate’s seat is canceled in a round because of failure to produce certain documents at a reporting center, the credentials of the candidate will be changed for future rounds, but the candidate will not have any kind of penalty in subsequent rounds.

10.7 Detailed algorithm for handling DS candidates as per 2015 rule

In 2015, the business rule specified that DS candidates should be given the best program they prefer subject to the constraint that there are only two seats for DS candidates per institute. Moreover, seats to DS category candidate needed to be allocated in a preferential manner from open category seats and creation of an additional seat (termed a “supernumerary allocation”) needed to be avoided to the extent possible.

Our algorithm for 2015 can be divided in two parts. The first part is the same as the current algorithm described in Section 4.3. After executing DA as described in Algorithm 2 while handling DS candidates as described in Section 4.3, we may have artificially increased the capacity of some (open category) programs by maximum of two seats per institute. Therefore, each seat which has been allotted from a DS virtual program is to be mapped to a virtual open program, and is thus processed one by one as follows. Let s be one such seat, say, in IITB,
and let $c$ be the candidate who has been given this seat. Suppose $c$ has been mapped to the EE program in IITB. Let $x$ be the candidate with the worst rank in the open category waitlist of the virtual program EE in IITB. If there is one more candidate in this waitlist with the same rank as the rank of $x$, then we just assign program EE to candidate $c$ and this completes the processing of seat $s$ (in a supernumerary manner). Otherwise, to take care of the over allocation, $c$ replaces $x$. We now run the DA algorithm with $x$ as the candidate not allotted any program (and so $x$ applies to the next program in her preference list). Note that $x$ may displace another candidate, and this may lead to a rejection chain.

However, in very rare cases, there is a possibility of an undesired condition arising out of this rejection chain. We now describe an example of a race condition that may arise while processing some DS candidates. Thereafter, we present a method for detecting a race condition. We conclude with a complete algorithm for handling DS candidates as per the 2015 rule.

### 10.7.1 Example of Race Condition

Let Amar, Akbar, Chetan, and Dhanush be four DS candidates. At the end of the DA algorithm, Amar, Akbar, and Chetan get their program through a DS seat; But Dhanush gets his program IITB-Electrical through a GE seat because there were already two better ranked DS candidates who got DS seats in IIT Bombay. Moreover, let Dhanush happens to be the last ranked candidate getting IITB-Electrical. Let Bharat, Krish, and Ekansh be the last ranked GEN candidates in IITD-Chemical, IITD-Metallurgy, and IITK-Mechanical respectively. The details of all these seven candidates with the programs allocated by the DA algorithm is shown in Figure 10.3.

| Candidate | GE Rank | Program          | Seat allocated | DS status |
|-----------|---------|------------------|----------------|-----------|
| Amar      | 1200    | IITD-Chemical    | DS             | Yes       |
| Akbar     | 400     | IITD-Metallurgy  | DS             | Yes       |
| Chetan    | 300     | IITK-Mechanical  | DS             | Yes       |
| Dhanush   | 200     | IITB-Electrical  | GE             | Yes       |
| Bharat    | 600     | IITD-Chemical    | GE             | No        |
| Krish     | 350     | IITD-Metallurgy  | GE             | No        |
| Ekansh    | 150     | IITK-Mechanical  | GE             | No        |

**Preference list of Dhanush**

- IITB-Electrical
- IITD-Chemical
- ...

**Preference list of Ekansh**

- IITK-Mechanical
- IITB-Electrical
- ...

Figure 10.3: Program allocation by the DA algorithm to 3 DS and 2 GE candidates.

We now describe the processing of Amar, Akbar, and Chetan who got DS seat. These candidates have to be given OPEN seats. In order to accommodate Amar, we need to remove Bharat and this leads to Bharat getting some other less preferred program in the rejection chain. In a similar manner, Akbar gets IITD-Metallurgy after removal of Krish and Krish gets some other less preferred program in the rejection chain. Let us process Chetan now. Since Chetan got seat IITK-Mechanical through DS quota we need to remove Ekansh from IITK-
Mechanical. Next preferred program for Ekansh is IITB-Electrical. Recall that Dhanush is the last ranked candidate getting IITB-Electrical. Notice that though Dhanush is a DS candidate, he got OPEN seat in IITB-Electrical. So Ekansh will remove Dhanush from IITB-Electrical. So Dhanush will apply for his next preferred program which is IITD-Electrical. There are already two DS candidates Amar and Akbar for IITD. Since Dhanush has better rank than Akbar, and Akbar has better rank than Amar, so Dhanush will remove Amar from DS virtual program of IITD. So the processing of Amar in the past goes waste since he is not getting a DS seat in IITD (the seat vacated by Bharat for Amar goes waste, the seat remained vacant in the end and Bharat got a less preferred program). A similar example can be constructed wherein the DS candidate who initiates a rejection chain will have to be de-allocated. In any such situation, we should revert the rejection chain and allocate the DS candidate a supernumerary seat. In the current example, Chetan has to be given a supernumerary seat in IITK-Electrical program.

10.7.2 Detecting Race Condition

After processing each seat \( s \), we need to check for race condition. Some key points to be noted about race condition are:

1. In the above example, if Dhanush had also applied for IITD-Chemical instead of IITD-Electrical, it would not have been a race condition. This is because, Dhanush will now simply occupy the space created by the processing of Amar in IITD-Chemical Open virtual program. Note that this doesn’t result in any program being vacant and hence there is no race condition.

   Thus, for race-condition-free allocation, candidates in a processed seat may change but their programs should not.

2. The number of candidates in any DS virtual program can be variable due to the rule of supernumerary allocation to same ranked candidates.

We gather that for any candidate \( x \) occupying a processed seat in old allocation (before processing of seat \( s \)), there must be a candidate \( x' \) occupying a processed seat in new allocation such that \( x \) and \( x' \) have the same DS virtual program and \( x.allotted\_program = x'.allotted\_program \).

If this condition does not hold after processing of a seat \( s \), we have a race condition and we will need to give the candidate occupying \( s \) a supernumerary seat.

To summarize, we need to verify that the allotted programs to processed seats in Old allocation of a DS virtual program constitute a subset of allotted programs to processed seats in New allocation of the same DS virtual program. If this holds true for all DS virtual programs, then we can proceed with processing further seats, otherwise we need to revert to old allocation and give a supernumerary seat to the latest processed DS candidate.

To check the above condition, after we process a seat, we iterate over processed seats in old allocation (including the latest processed seat), for each allotted program of a processed seat, we find a matching processed seat in new allocation with the same allotted program. If at any point, no such match is found, we declare that there is a race condition and we need to revert to old allocation (before the processing of latest seat) and make one supernumerary seat.

10.7.3 Pseudocode

We now provide full details of the algorithm in this section.
Details of the algorithm

The algorithm maintains the set $D$ of seats in all DS programs. Since, due to ties in multiple DS candidates, number of seats in any program may change during the course of the algorithm, we keep $D$ as an instance of ALLOCATION object. The algorithm processes the seats from $D$ sequentially. At each stage, it also maintains a flag Is_processed (initialized to false) for each seat in $D$. After processing a seat, this flag is set to true. It picks an unprocessed seat $s$ from $D$ and does the following. Let $x$ be the candidate occupying the seat $s$ and $p$ be the program opted by him/her. Let $w$ be the worst rank candidate from OPEN category who has been assigned program $p$. $w$ is removed from program $p$ and the capacity of $p$ is reduced by 1. We now start DA algorithm with input $\{w\}$. Effectively, the candidate $w$ applies to the next program in his/her preference list. This generates a rejection chain resulting in a different allocation than before. Let the allocation before processing be OLD-ALLOCATION and allocation after processing be NEW-ALLOCATION. It is quite possible that the candidate corresponding to any processed seat in NEW-ALLOCATION.$D$ is different from that in OLD-ALLOCATION.$D$. However, if the set of programs associated to the processed seats of NEW-ALLOCATION.$D$ differs from that in OLD-ALLOCATION.$D$, we revert to NEW-ALLOCATION, create a supernumerary seat for $p$ and allocate it to $x$.

We need to consider each DS seat one-by-one, create their respective rejection chain and revert it if it causes race condition. To detect race condition after processing a seat $s$, all we need to do is to check if the multiset $S_1$ of allotted programs to processed seats in OLD-ALLOCATION is a subset of the multiset $S_2$ of allotted programs to processed seats in NEW-ALLOCATION. Note that, there cannot be a new processed seat created in NEW-ALLOCATION (s is marked processed in both OLD-ALLOCATION and NEW-ALLOCATION). Hence, $|S_2|=|S_1|$. Therefore, in order to detect race condition, all we need to do is to verify whether $S_1 = S_2$. If $S_1 \neq S_2$, then there is a race condition, else there is no race condition. Notice that $S_1$ and $S_2$ are multi-sets and so they should be matched element by element for equality. An element is a program (i.e. IITK_CS, IITK_CE etc. That is, consider branch names augmented with institute names).

Algorithm 3 presents the complete pseudocode of the algorithm for handling the rule for admission of DS candidates.

Notations

- $\text{CANDIDATE}(s)$: candidate to whom DS seat $s$ is allocated. Set to $\phi$ if the seat is unoccupied.
- $\text{PROGRAM}(s)$: OPEN virtual program corresponding to program allocated to candidate occupying DS seat $s$. Set to $\phi$ if the seat is unoccupied.
Algorithm 3 Algorithm to incorporate the rule for admission under DS category

INPUTS:
The regular inputs for DA.
The Boolean supernumerary-ok, which indicates whether a supernumerary seat may be created if a DS related problem occurs. Initially we run with supernumerary-ok=False
Each seat has a Boolean flag Is-Processed. We initialize it as Is-Processed=False for all DS seats.

OUTPUTS:
The regular output of DA, as well as the waitlists for the DS virtual programs (these include the name of the actual program allotted to each candidate).
The list of stained programs S. If non-empty, this would be a trigger to get permission from the JAB Chairman and rerun with supernumerary-ok = True.

1: for all Institutes do
2:   Create a DS virtual program I.
3:   c(I) ← 2
4:   MERIT(I) ← DS candidates in CML in CML order
5:   WaitList(I) will be an augmented waitlist, such that each entry will contain both a candidate as well as a program name.
6: end for
7: for all candidates x with DS tag do
8:   Create Pref(x). For each program, first list virtual programs as usual as per birth category of x, then list corresponding institute DS virtual program (tag it with the relevant program).
9: end for
10: Run the DA algorithm
11: Allocation ← WaitList(p) ∀ p ∈ P and i(x) ∀ x ∈ A as per the output of the DA algorithm
12: Allocation.D ← List of seats in all DS programs in Allocation. A seat data-structure includes a candidate, a program, and a Boolean flag Is-Processed.
13: for all s ∈ Allocation.D do
14:   s.Is-Processed ← false
15: end for
16: S ← Empty list ▷ List of stained programs S is needed only if supernumerary-ok = False
17: while ∃s ∈ Allocation.D with (|s.Is-Processed|= false and CANDIDATE(s) ≠ φ) do
18:   OLD-ALLOCATION ← Allocation;
19:   L ← PROCESSSEAT(s)
20:   Q ← Empty queue

10.8 History and background
This appendix provides some background regarding the institutions and examinations involved.
for all $y \in L$ do
Remove $y$ from $\text{WaitList}(p)$
$\text{REJECT}(y)$ $\triangleright$ This adds $y$ to $Q$ as well
end for

Run DA with current $i(x')$, $\text{WaitList}(p)$ and $Q$ as inputs (other inputs as usual).
During the run, if a DS candidate $x''$ is pushed out of a DS seat and the set of programs associated with the processed seats in that DS virtual program changes, add the corresponding OPEN virtual program to a list $S$ of stained virtual programs.

$\text{ALLOCATION} \leftarrow \text{Output of DA}$ $\triangleright$ DA may maintain a list of affected DS virtual programs to make the loop below more efficient

$\text{TO-REVERT} \leftarrow \text{IsRaceCondition}(\text{ALLOCATION}, \text{OLD-ALLOCATION})$

if $\text{TO-REVERT}$ then
if supernumerary-ok then
$\text{ALLOCATION} \leftarrow \text{OLD-ALLOCATION}$
Increment $c(p)$ by 1;
else
Do nothing $\triangleright S$ now includes both programs that lost a DS candidate after making room, as well as those that gained a DS candidate and may have a supernumerary seat (but will not be processed by the algorithm since that seat has been already processed).
end if
end if

$\text{ALLOCATION}.D \leftarrow \text{List of seats in all DS programs according to } \text{ALLOCATION}$
end while

return $\text{ALLOCATION}$ and $S$; $\triangleright$ Note that if a DS candidate has gotten a seat via DS in program $p$, he is not included in $\text{WaitList}(p)$. This must be read separately by reading the augmented waitlist $\text{WaitList}(I)$ (which specifies both the candidate and the program) where $I$ corresponds to the institute that hosts $p$. 

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function \textsc{processSeat}(s)
\begin{align*}
 & s.\text{Is-Processed} \leftarrow \text{true}; \\
 & x \leftarrow \text{\textsc{Candidate}}(s); \\
 & p \leftarrow \text{\textsc{Program}}(s); \\
 & \text{Decrement } c(p) \text{ by 1;} \\
 & L \leftarrow \text{List of all candidates who must be rejected from } \text{\textsc{WaitList}}(p) \text{ based on updated capacity, } \text{\textsc{Min-Cutoff}}(p) \text{ etc.} \triangleright \text{In case of no ties, } L \text{ will contain one candidate if the last candidate does not clear } \text{\textsc{Min-Cutoff}}(p), \text{ and zero candidates otherwise.} \\
 & \text{Return } L \\
\end{align*}
end function

function \textsc{IsRaceCondition}(\textsc{new-allocation},\textsc{old-allocation})
\begin{align*}
 & S_1 \leftarrow \text{multi set of allotted programs to processed seats in } \textsc{new-allocation}.D \triangleright \text{a program is institute+branch} \\
 & S_2 \leftarrow \text{multi set of allotted programs to processed seats in } \textsc{old-allocation}.D \triangleright \text{a program is institute+branch} \\
 & \text{if } S_1 = S_2 \text{ then} \\
 & \quad \text{return False;} \\
 & \text{else} \\
 & \quad \text{return True;} \\
 & \text{end if} \\
\end{align*}
end function

Students in India must write a senior high school graduation exam (known as the “Board exam”); these are administered by the educational board to which their high school is affiliated. However, these exams necessarily account for the wide heterogeneity in the preparation of students across schools and geographies. Hence, scores in these exams are typically not considered appropriate for determining admissions to the country’s most prestigious engineering colleges.

**History of admissions to the IITs.** The first five IITs (Kharagpur, Bombay, Kanpur, Madras and Delhi) were founded during 1951-61, and almost immediately they created a countrywide Common Entrance Examination for admissions purposes. The examination was used to produce a single ranking called a “Merit List” of candidates (more precisely, one Merit List for each “category” of students, see Table 4.1). Next, in a centralized process, candidates were then considered in the increasing order of rank (starting with the top ranker), and allotted their most desired program which was not already full based on the preferences over programs that they submitted after “counselling” at the closest IIT. [This mechanism is known as Serial dictatorship, e.g., see [2] The name of the examination subsequently changed to Joint Entrance Exam (JEE), and the number of IITs has grown to 23. As the number of candidates grew, the IITs resorted to a two stage examination process, with the first “screening” stage used to select a subset of candidates who could then write a more detailed second stage exam.

**History of admissions to the non-IIT CFTIs.** Starting in 1959, Regional Engineering Colleges (RECs) were created in every major state to supplement the IITs. The admissions
to these colleges was conducted in a decentralized manner and many of them conducted their own entrance exams, creating a logistical nightmare for high school students who were aspiring engineers. In 2002, the RECs were renamed National Institutes of Technology (NITs), and a single All India Engineering Entrance Examination (AIEEE) was created to centralize the examination and admissions process for the NITs, simplifying the logistics. (There are now 31 NITs.)

Several Indian Institutes of Information Technology (IIITs) were established starting in 1997; that exclusively offered programs allied to information technology. (There are now 23 IIITs.) Admissions to the IIITs as well as other engineering colleges funded by the central government were clubbed with admissions to the NITs.

**Merger of Examinations.** Subsequently the AIEEE was merged with the first stage of the two stage IIT exam process in 2012. The first examination is called the JEE Main. The JEE Main score of candidates is used as follows:

1. The non-IIT CFTIs use the JEE Main scores to construct their Merit Lists and determine allocation of seats at the non-IIT CFTIs. Until 2016, the Merit Lists were created by a combining the JEE Main score of a candidate with her Board exam score. Since 2017 they are exclusively based on the JEE Main score.

2. The IITs use the JEE Main scores to determine a subset of about 150,000 candidates (as of 2015) who qualify to be permitted to write the second stage “JEE Advanced” examination.

The JEE Advanced examination is conducted subsequently by the IITs for their own admissions purposes, and typically consists of three separate exams for Physics, Chemistry and Math. Subject cutoffs are set for each of the three, and a Merit List of candidates who clear the cutoff is constructed based on their total score across the three subjects for purposes of admission to IIT programs. (Detailed tie-breaking rules ensure that ties in the Merit List play a negligible role, and similarly for the Merit Lists for the non-IITs umbrella.) The Board exam score of candidates is not used for ranking but purely to determine their eligibility based on a cutoff.

From 2012 to 2014, the seat allocation process for IITs (under IITs umbrella) remained separate from that for the non-IIT CFTIs (under non-IITs umbrella). The IITs conducted their admissions first, even before the Board exam scores had come in (since almost all successful candidates obtained the requisite Board exam score), and the non-IITs umbrella conducted its admissions process subsequently.

**Merger of Seat Allocation processes.** After the merger of examinations, an external nudge in the form of a public interest court case W.P.(C) 2275/2010 in the Delhi High Court (demanding coordination to reduce vacancies) caused the creation of a joint seat allocation process.

Following a false start in 2013, a common seat allocation process for all the CFTIs including the IITs was launched in 2015, run by the Joint Seat Allocation Authority (JoSAA). This joint seat allocation process is the subject of the current paper. JoSAA provided candidates with a single window for admission to any of the over 80 CFTIs.
Design Insight. Centralization can greatly reduce the logistical burden of participation on both sides of the market (in addition to improving the allocative efficiency and reducing market congestion if the allocation is also done centrally).

Related efforts elsewhere include the Common Application for applying to hundreds of colleges worldwide (in this case the allocation is not done centrally), centralized school admissions, and centralized labor markets (see Section 2.3). In the case of the CFTIs, centralization has occurred for the examination, application as well as the seat allocation processes.

In 2015 and 2016, the JoSAA seat allocation process was conducted after the JEE Main, JEE Advanced, and Board exam scores became available. Delays in announcement of Board marks was a major issue, indeed the joint process was very nearly called off the very first time in 2015 due to such delays. The IITs wanted to proceed with their allocation, whereas the other institutes were unable to rank candidates without Board marks being at hand.

Design Insight. Aggregation of all relevant information and alignment of timelines of the concerned institutions can be bottleneck for centralized matching/allocation. If institutions construct their preferences based on the same information (and at the same time), this improves the chances of successful centralization.

Since 2017 the non-IIT CFTIs chose to stop using Board exam scores for constructing their Merit Lists, eliminating this issue, consistent with the trend of logistics getting simpler over time.

In Appendix 10.8.1 we briefly discuss the broader impact of the JEE. We emphasize here that our mandate was restricted to designing an efficient and fair joint seat allocation mechanism for the 80+ institutions involved (the CFTIs), that respects a set of business rules, treating the JEE as a given.

10.8.1 Broader view of the Joint Entrance Examination (JEE)

The entire examination and seat allocation system for the CFTIs in India under JoSAA based on the JEE is generally viewed as providing a good solution to the problem of resource allocation in a supply constrained environment. It is heartening that allegations of cheating in the examination are highly atypical despite that 1.3 million candidates write the JEE Main each year, and allegations of corruption in terms leaking of exam questions or grading malpractice are similarly atypical, despite the extremely high stakes. The exam is also viewed as being fairly successful at identifying talented candidates (however, many candidates may not really be interested in engineering; a large fraction of successful candidates see an engineering education as a stepping stone to lucrative careers in other fields).

The main questions that do arise about this system are around the demands and incentives it generates for candidates and the JEE coaching industry that has grown exponentially around it. Some of the concerns that have been voiced are: (i) Wealthy candidates have an increasing advantage due to coaching classes becoming increasingly adept at systematically preparing candidates, and charging very high fees. (ii) Candidates are “burned out” even before they start their studies at these institutes due to at least two, many times three, and often six years of extremely intense preparations merely in order to gain admission. As such, they often do not invest in their education as engineers, and a majority of them do not work in or around the area for which they are trained. Instead, they go into consulting, finance and information...
technology. (iii) Related to the above, candidates may “lose” years due to repeating the JEE after they have graduated from senior high school. (Previously, candidates would commonly lose multiple years and write the JEE three times, for instance. Since 2010, the rules prohibit writing the JEE Advanced more than one year after completing the 12th grade, whereas the JEE Main can still be attempted up to two years after.) There are no ready solutions for these issues. Reservation of seats for different categories of students (see Chapter 4) is obviously a hot button topic which is heavily debated by stakeholders, observers and the government alike. We remark here that changes to the examination system and the reservation rules are serious issues that were fully outside the scope of the joint seat allocation project that this paper describes; we are providing a description here merely to provide the interested reader with some context. Our mandate was to design a seat allocation process with high allocative efficiency that while preserving good properties of the legacy mechanisms such as fairness, i.e., a candidate with a better rank in the relevant Merit List should not be denied admission to a program if another candidate with a lower rank was granted admission to that program.

10.9 The challenge and the opportunity of overbooking

The fraction of Rejects from among fresh allocations is quite large, especially in later rounds. One may think of using yield prediction (i.e., admitting more candidates than the capacity of the program) as a way to improve the efficiency of allocation and to have less vacancies at the end of all the main rounds. This is harder than it would seem, despite the fraction of rejected fresh allocations being 60% or more in later rounds. Consider Round 3 in 2015. There were 7342 candidates whose allocation changed including 3720 fresh allocations. There were 2666 Rejects, almost all (2651 of them) from among the fresh allocations, meaning that 71.6% of fresh allocations were rejected! It is tempting to think that one can use yield prediction to substantially take care of the issue of Rejects. Unfortunately, this does not work out as expected. Even for an individual program whose size may be 50 or 100 seats, a lot of virtual programs (split by category and further by Home State vs All India quota for NITs and many CFTIs) – with the exception of the OPEN and sometimes the OBC virtual programs – have a single digit number of seats, minimizing our ability to benefit from yield prediction when overage (i.e., admitting more candidates than the number of seats) is a problem. In fact, if we consider the subset of virtual programs with 10 or more rejected seats in that round, this accounts for only 740 of the 2666 Rejects. Thus, roughly, one could only hope to account for about 30% of the Rejects (roughly those that occur in virtual programs with 10 or more Rejects, since with 5 Rejects, Poisson(5) has a reasonable likelihood of being 0 and even more chance of being 1, so there is minimum benefit from yield prediction), without risking significant overage. 60 – 80% Rejects are present across categories, though the OPEN category has slightly higher fraction of Rejects closer to 80% and accounts for 1647 of the Rejects, meaning more than 60% of them. We do notice some patterns like if there are 4 or more fresh allocations then there is at least 1 Reject, if there are 6 or more fresh at least 2 Rejects, with 10 or more fresh at least 40% are Reject and with 20 or more at least 70% are rejected. Such observations may be the basis of refined business rules for conservative yield prediction to improve the efficiency of allocation. Use of an opaque/complex predictive model is not desirable due to lack of transparency and possibility of unfairness etc. In this context, it is imperative that the business rules must be transparently and completely specified, and be clearly fair to all concerned, in accordance with...
the prevailing laws. So far, this option has not been considered. However, it may be worth considering, based on the following reasoning: currently, about 70% of vacancies in a given round persist until the next round. So over two rounds, the number of vacancies is reduced to about 70% of 70% = half. Instead, suppose we use some conservative yield prediction as above, and it reduces the vacancies in the resulting allocation by about 30%. This means that now, 70% of (100 − 30)% = 50% of vacancies in a given round persist until the next round. Over two rounds then, the number of vacancies is reduced to about 50% of 50% = 25%. The cost of doing this would be, in worst case, a handful of seats allocated in excess of capacity, maybe about 10 in total (though we would aim for 0 supernumerary based on data from the previous year). In a system with over 30,000 seats, this would appear to be a very small aberration. On the other hand, the benefit may be substantial: In 2017, 4168 candidates withdrew in the reporting following the Round 6 allocation. After Round 6 there was only one more main round (Round 7), so 70% or more of these 4168 seats (i.e., over 3000 seats) remained unfilled at the end of all the main rounds. Note that Round 5 happened only two days before Round 6. One would expect that if withdrawal was permitted only until Round 5, then most of these 4168 candidates (say, 4000 of them) would have withdrawn by then, and then with two more main rounds of seat allocation with conservative yield prediction as above, only 25% or about 1000 of these vacancies would have remained at the end of the last main round (Round 7). Similarly, under such an approach, the vacancies resulting from rejected seats would also be more effectively dealt with.

Finally, we remark that steps should be taken to ensure that only serious candidates participate in the last rounds of admission after the Withdraw option is closed. For example, if a candidate wants to participate in such a round, she should be required to explicitly state that. Currently, all unallotted candidates are a part of future rounds by default. Making the candidate report physically, or pay the fee upfront could be a powerful tools to filter candidates who are not serious.
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