VERIFYING AND CODIFYING STRATEGIES IN THE KNNKP(h) ENDGAME*

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ABSTRACT

The extreme complexity of chess endgames with five or more men occasionally tempts human experts into making necessarily *incomplete* and sometimes erroneous statements. To some extent, increased computational speed and expanded memory, when combined with a full-width backward-chaining procedure nowadays may result in databases which embrace *complete* knowledge over a certain endgame domain. The major remaining problem after having obtained such knowledge is not (trivially) indicating the best move, but explaining *why* this move should be best. In other words: the true task is the formulation of rules and strategies implying *how* the endgame should be played.

The present article broaches the subject by verifying, via a database, two statements of Troitzky's (1934) about the domain KNNKP(h). The statements are found to be unassailable in all details. The present work extends Troitzky's by a few maximin results. Depth charts (Roycroft, 1986) are discussed as a potential limited aid towards formulating a strategy. The new notion of *tablebases* is introduced, whereas a slight generalization in tablebase construction permits a relatively comfortable way of verifying strategies.

1. BACKGROUND

Only a short time ago, the game of chess was a research area in which AI workers without specific chess knowledge could achieve significant results. Notably, AI techniques (representation, search heuristics including their sophisticated refinements, etc.) were tested in endgame domains of three or at most four pieces. Anything beyond this number was practically excluded by the extreme complexity and huge fast-storage requirements. The construction of omniscient databases as described by Van den Herik and Herschberg (1985) and Thompson (1986) was the subject of a breakthrough by the advent of supercomputers dealing with the complexity in reasonable time and the availability of mass storage putting an end to the prevailing storage limitations (Dekker *et al.*, 1987a; Van den Herik and Dekker, 1988).

Though it is of the essence in database construction that complete knowledge is obtained by an exhaustive enumeration via full-width backward chaining (Van den Herik and Herschberg, 1985), heuristics seemed to have a role to play in the construction of an endgame involving five or more pieces, whenever such an endgame converts to a different one. (Dekker *et al.*, 1987a; Van den Herik *et al.*, 1987).

Current developments, though, seem to indicate that, at least in some cases, heuristics with the uncertainty they are bound to introduce can be eliminated. This elimination, automatic in the sense of *programmable*, promotes the domain to which it is applicable from high plausibility to verifiable certainty. The work leading to this reduction of uncertainty for five-men endgames with at most one Pawn is due to Stiller (1988, 1989). This has very recently been generalized by Dekker (1989), who allows an

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arbitrary number of Pawns to be included among the *n* pieces, albeit the computer speed limits its applicability to $n \leq 5$ at present writing. Dekker has constructed a generic endgame-database-building program, which, in theory, is able to construct the 32-piece endgame. During construction of a database his program can be set to consider castling as well as *en passant* capture, though it does not consider the 50-move rule.

To end our digression and to summarize the results of Complexity Starts at Five (Dekker *et al.*, 1987a), we recall that the construction of the KNNKP(h) endgame uses a prospective analysis over all subdomains adjacent to the KNNKP(h) domain and reachable by conversion therefrom. These conversions, ten in number, may be grouped into four classes of subdomains, viz. (1) KNNKA (2) KNKP (3) KNNK (4) KNKA, in which A stands for *A*ny of Q, R, B, N. Determining potential final positions is considerably simplified by noting that class 3 and class 4 can be safely excluded. This assertion is proved by classes showing that the set of continuations in class 3, *in so far as it results from KNNKP(h)*, is empty in a certain sense; so is class 4. This assertion is proved in Dekker *et al.* (1987a) by eight *lemmatics*, where the latter term is defined as involving theorems and proofs of heuristic assumptions. The emptiness of the classes is equivalent to the statement that within the classes excluded, while it is true that White can mate, this side cannot do so without Black's departing from optimal counterplay. Since prospective endgame analysis assumes optimal play by both sides, the classes are safely excluded from the analysis. Processing the result of this prospective analysis, the retrospective relations between KNNKP(h) and its adjacent domains are depicted in Figure 1. An arrow indicates a possible conversion *from* KNNKP(h) to the adjacent domain involved in the inverse sense.

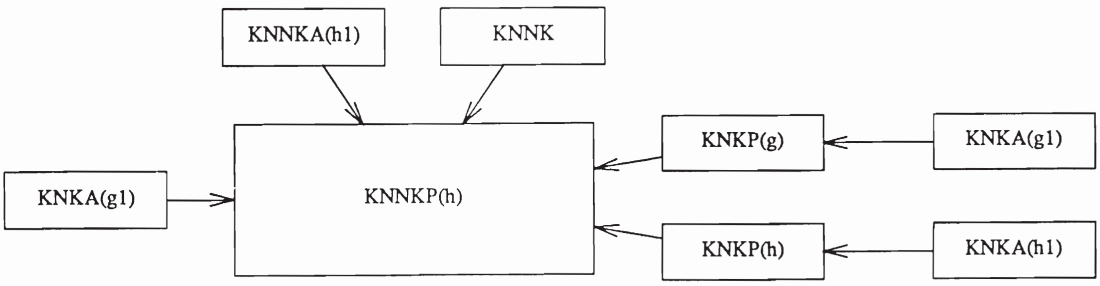

Figure 1: Retrospective relations between the KNNKP(h) domain and its adjacent domains.

The result of the backward-chaining enumeration is a database of ($7 \times 64^2 \times \binom{64}{2}$ =) 57,802,752 positions.

The implementation of the database is a *packed linear one-dimensional array*, say M, in which the index, say j, of each array element is a suitably chosen bi-unique mapping of a board configuration. The contents of M [j] (eight bits) by convention are:

-1 for an illegitimate position

0 for a drawn position

n for a win-in-*n* position, $n \leq 254$,

disregarding the 50-move rule which has been the subject of Dekker *et al.* (1987b), now published as Dekker *et al.* (1989). The (~60 Mbyte) database having been constructed, it is a trivial matter to determine the (an) optimal move for any position. (There may be several equipollent optimal moves.)

The major issue, though, is to find an acceptable justification for the database-derived move being optimal. In this sense acceptability is defined in terms of grandmasters' notions, - after all, these are the human experts in the domain. To paraphrase: while it is true that *locally* the database explicitly holds perfect information, *globally* speaking it is incapable of formulating a strategy. Yet it is our belief that such a strategy *must* exist, however implicitly.

2. HUMAN-EXPERT ANALYSIS

A.A. Troitzky (1866-1942), whose fame rests on the endgame studies he composed, has spent a major part of his life in Russia in the investigation of the intricacies of the KNNKP(h) endgame. We quote two of his principal results (Troitzky, 1934) as statements A and B below.

2.1. Safe Blocking of the Pawn on h4

Following Troitzky (1934) we refer to Diagram 1, essentially condensing 8 different endgames (or 4 if symmetry with respect to the mid-board vertical is considered). Troitzky's statement A reads:

> "The endgame is won for White provided the black Pawn is no more forward than the positions indicated for the various Pawns in Diagram 1 **and** *the Pawn is safely blocked.*"

DIAGRAM 1
The extreme black Pawns positions.

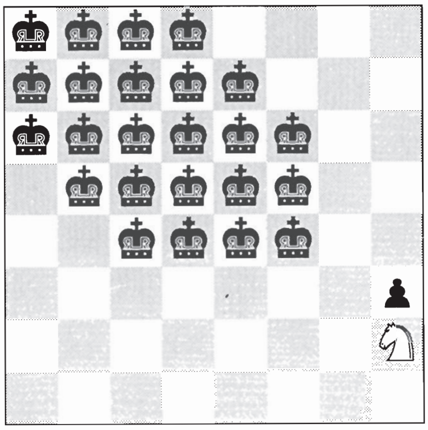

DIAGRAM 2
The Troitzky zone.

Again following Troitzky, the notion of being *safely blocked* amounts to two simultaneous conditions, viz.

- that White can protect the blocking Knight when the latter is attacked by the black King **and**
- that neither of the Knights can be the victim of a forced capture by Black.

2.2. The Troitzky Zone

By statement A, the position is *always* a win for White provided the Pawn is *safely blocked* on h4, h5, h6 or h7. Blocked Pawns on h3 and h2 are special cases. Troitzky (1934) has made a profound analysis of positions with the Pawn on h3 and concluded that some of these still are won, whereas some others are drawn, but only just! The crucial discriminant is whether the black King can move to the corner square a8 *in time*. Troitzky asserted that there is a contiguous area for the black King to occupy such that Black can reach the safe square a8 without problems. This area, dubbed the safety zone by Troitzky, has since become known as the Troitzky zone (see Diagram 2). Troitzky's second statement B can be paraphrased as:

> "Whatever the positions of the mobile Knight and the white King, the game is drawn whenever the black King is within the Troitzky zone."

3. COMPUTER VERIFICATION OF TROITZKY'S STATEMENT A

In the past few years, the chess world more than once has been faced by computer analyses that essentially improved chess theory as it was accepted up to then (Thompson, 1986; Van den Herik *et al.*, 1987). This circumstance made it plausible that human statements about very complex problems would contain some, possibly minor, errors. This circumstance motivated us to investigate to what extent Troitzky's statements would stand against the omniscient database constructed previously. Describing the steps of this investigation below, we have attempted to draw the reader into the spirit of our quest as it developed.

3.1. Determining the Winning h-Pawn Ranks

In the chess world, the statement that a certain type of position is "always" won regrettably often means that the position is generally won except for special circumstances. These special circumstances have been found to occur in the precise interpretation of the notion *safely blocked* in statement A. A trivial instance of such a special circumstance forcing a different interpretation of *safely blocked* is hinted at by the position [WK a1, WN h3, WN a8; BK c6, BP h4], in which White is bound to lose his Knight. This shifts the problem from the definition of *safely blocked* to the definition of a *forced capture*. This example, trivial to a chess-player, arouses the suspicion that more such special circumstances may be found and may be less trivial to the human expert. This gives rise to a subproblem of how to list (exhaustively!) all positions to which the special circumstances apply. Evidently, manual determination of the special circumstances is out of the question and the task before us is constructing a program effectively capable of listing, more generally, all configurations satisfying a given (special) class characteristic. As a tentative definition of these special circumstances, we intuitively singled out four classes of special configurations, viz.:

1. Black captures a Knight;
2. Black chases away the blocking Knight;
3. enforced repetition of positions;
4. the immobility of both Knights.

Initially, only classes 1 and 2 were identified as classes of special configurations (i.e., classes to which special circumstances would apply), because they most obviously sprang to mind. However, as the investigation progressed, we stumbled on classes 3 and 4, even though these arose in a different context. To us, these findings imply that it cannot be excluded in principle that other classes do exist. Still, we did not see our way to define them conceptually on the mere existence of the database available to us.

3.2. The Tablebase Technique

An exhaustive enumeration of the positions of class 1 may, in principle, be done by any of three techniques.

(a) We singly consider all drawn positions from the database and determine whether an n-ply prospective search involves losing a Knight. This technique is profligate of computer time, firstly because we have to search to n ply with n unknown in advance and possibly large, secondly because perusing the database may well lead to useless repetition of search by reason of identical subtrees having to be searched time and again.

(b) We construct a database in the usual representation, the goal state not being "White mates" but "Black captures a white Knight". This again requires some 60M bytes of storage. The attendant disadvantage here is that almost all entries will contain a 0 (zero), corresponding to configurations in which no Knight can be captured. The reason simply is that there is only a handful of configurations in which a Knight *can* be taken.

(c) We build a *tablebase* containing relevant positions only. In this context a *relevant* position is a position in which **either** one of the Knights can be captured **or** in which the Knight is *forced* to take the Pawn. (Chess theory informs us, and databases do confirm that the successor game KNNK then is drawn.)

We have opted for the *tablebase* approach. The tablebase is a two-dimensional array, named C for capture information. In the first column of C, the *key field*, we record the configurations' representation, in the second column of C, the *distance field*, we note the corresponding number of moves to either knight capture or pawn loss. The number of paired entries is not known in advance but is strictly limited to the number of rare configurations where these captures or losses can occur.

Building the tablebase is closely analogous to building a conventional endgame database. Initialization is by recording all configurations leading to the capture/loss indicated in one move. Subsequently we search for all positions leading to this result in *two* moves. The process extending the number of moves terminates as soon as no new such positions are found for the next tentative value of the distance field.

3.3. Combining Tablebases

For the special configurations of class 1, the tablebase *takeknight* was constructed; similarly to the procedure in the database, the convention obtains that in the position stored in the key field, White is to move (WTM). With *takeknight* in hand, it was found expedient to renounce construction of a distinct tablebase for class 2, because it may well happen that Black aims a combination of goals. For instance, Black may first threaten to enclose a Knight in a corner (the class 1 goal) and, if prevented from doing so by White, may still pursue the goal of chasing away the blocking Knight. This type of position (goal 1 having been frustrated shifting to goal 2 or conversely) could well fail to be recorded in any tablebase, barring special devices. Schoo (1988) has shown that the problem can be overcome by the construction of the tablebase *badblocked* which allows for such a combination of goals. Accordingly, *badblocked* was constructed.

3.4. Confronting the Tablebase with the Database

By construction, *badblocked* enumerates all *not-safely blocked* positions common to classes 1 and 2. It is now a valid research goal to try and find additional drawn positions in which the Pawn is *not safely blocked*. For this purpose we inspect all positions in the database in which the Knight is blocking the Pawn and which have been recorded as drawn. Next, these positions are searched for in *badblocked*. There are now precisely two mutually exclusive possibilities:

(a) if the position in question occurs in *badblocked*, we evidently have a configuration which is drawn by reason of the Pawn being *not safely blocked*;

(b) if the position in question fails to occur in *badblocked* we have a drawn configuration, which by our preliminary interpretations of *safely blocked* would be a *safely blocked* **drawn** position!

Positions coming under b intrigued us. Their occurrence might point to:

(i) the incorrectness of the characterizations we chose for *safely blocked*;

(ii) the existence of concepts other than those so far considered which yet play a decisive role in the outcome;

(iii) the falsity of Troitzky's statement A.

The confrontation of the database with *badblocked* resulted in finding 119 positions absent from *badblocked*, while yet the database indicated a draw.

Table 1 presents them, broken down by the positions of the blocking Knight and the blocked Pawn.

blocking WN	black Pawn	# of positions
h6	h7	61
h5	h6	9
h4	h5	21
h3	h4	28

Table 1: Discrepancies between the database and *badblocked.*

The limited number of 119 allowed visual inspection of the discrepant positions. It turned out that both (i) and (ii) were at the root of these discrepancies. When investigated more closely the following was found.

1. When constructing *badblocked* we had blithely assumed that, provided no unprotected Knight is under attack, none of the Knights can be captured on the next move. The position of Diagram 3 shows that this assumption was unjustified. (In this position the black King does not threaten the Knight on h3, because the latter is protected by the white King. Yet the black King is able to capture the Knight on the very next move because the white King is in check. As a consequence, the Knight no longer is protected and may then be captured by the black King.)

2. The remainder of the positions turns out to be drawn by an amazing stalemate strategy: one of the Knights is under attack and White, on trying to preserve this Knight, stalemates Black. An example is provided in Diagram 4: White may protect the blocking Knight by moving Kf2-g3, resulting in Black's being stalemated "pat in the middle of the board".

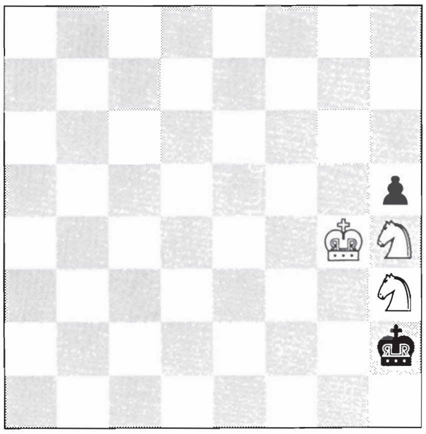

DIAGRAM 3
White (WTM) loses a Knight.

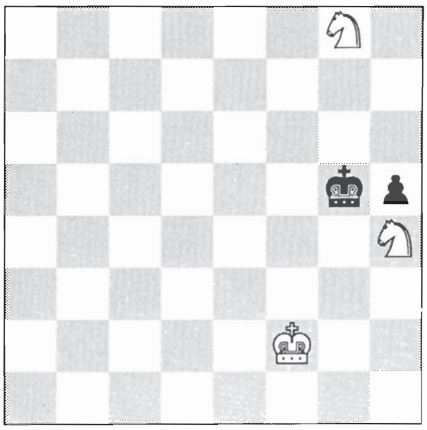

DIAGRAM 4
A draw by a surprising stalemate strategy (WTM).

An exhaustive check showed that on this closer analysis, all 119 positions should have been characterized as *not safely blocked.* This is due to the loss of a Knight in group 1, to the sacrifice of a Knight in group 2 if White is to avoid stalemate.

Moreover, we may infer that there are no positions coming under class 3 of Section 3.1, which implies repetition of positions. Similarly, the nullity of class 4 is evident, because there are only two mutually exclusive possibilities:

- **either** one of the mutually protecting Knights blocks the Pawn, in which case the position is won with the Pawn on h4, h5, h6 or h7
- **neither** of the Knights (again providing mutual protection) blocks the Pawn, in which case the position is irrelevant for the investigation.

3.5. Troitzky's Statement A Confirmed

The foregoing has shown that every *drawn* position with a blocked Pawn on h4, h5, h6 or h7 always is *not safely blocked* . Rephrasing this, we have found that there are *no* positions which are both drawn **and** *safely blocked.* As a corollary, there is no position disproving Troitzky's statement A. For completeness sake, we still have to prove that draws exist in which the Pawn is *safely blocked* on h3. Troitzky's statement B, constructively defining the existence of a safety zone, however, is a strong pointer to the occurrence of draws with a *safely blocked* Pawn on h3.

As a result of our researches, we are in a position to append a qualification to Troitzky's statement A.

Statement A1:

> "The maximin of all combinations in which Black may capture a Knight or may chase away the blocking Knight is 4 moves for a blocked Pawn on h3 to h7 inclusive." (Schoo, 1988, p. 21)

4. COMPUTER VERIFICATION OF TROITZKY'S STATEMENT B

4.1. The Verification of the Extent of the Troitzky Zone

Verifying or falsifying the correctness of the extent of the Troitzky zone, with a fixed Pawn on h3 and therefore a blocking Knight on h2, is a simple problem in computer terms. In passing we note that discrepancies as per Table 1 do *not* arise with the Pawn on h3. For each BK position we determine the number of legitimate won positions with arbitrary but legal placements of the WK and the non blocking WN. When divided by the total number of legitimate positions involving the BK position under investigation, we obtain a fraction which may be regarded as the probability of a win. Converting to percentages and rounding to the nearest integer, the results are inscribed in Diagram 5. Where the Diagram shows the symbol for BK, the percentage is an unrounded, exact zero. To rephrase: should BK be found on such a square, the position can *never* be won for White. The crosses (on f1, f3 and g4) indicate the illegitimacy of the BK ever being found there under our assumption of WTM.

♚	♚	♚	♚	<1%	3%	14%	26%
♚	♚	♚	♚	♚	<1%	4%	19%
♚	♚	♚	♚	♚	♚	2%	10%
<1%	♚	♚	♚	♚	♚	1%	11%
3%	<1%	♚	♚	♚	♚	X	14%
13%	3%	<1%	<1%	<1%	X	4%	♟
26%	18%	10%	8%	11%	11%	12%	♘
46%	39%	29%	24%	23%	X	23%	27%

DIAGRAM 5
Troitzky's zoning laws as confirmed.

We find that the BKs as shown in Diagram 5 *exactly* correspond to the Troitzky zone as given in Diagram 2. This in turn implies the *complete correctness* of Troitzky's statement B, published as long ago as 1934 and hence without the benefit of computer assistance. This is an impressive achievement, the more so because the area outside of the Troitzky zone contains squares which have less then 1% chance of winning. We can safely infer that Troitzky must have discovered these rarest of all positions and must have been aware of how to convert them into a win. Our admiration knows no bounds.

4.2. A Rudimentary Strategy for Searching the Troitzky Zone

Section 4.1 in effect has shown that with the h3-Pawn *blocked* and the BK in the Troitzky zone, the position is drawn. It follows that positions from which the BK can reach the safety zone are also drawn. A fascinating investigation now arises: under what conditions, given a blocked h3-Pawn, can a position be characterized as a draw? In order to provide a partial answer to the question we stipulate from results previously obtained in this paper that given a blocked h3-Pawn, the following classes of positions are *certainly* drawn:

(a) the BK is within the Troitzky zone **or**

(b) the BK can reach the Troitzky zone **or**

(c) the BP is *not safely blocked.*

It is well worth remarking that if a position comes under none of (a), (b) or (c), it should be regarded as **not** (*yet*) classified and definitely **not** as automatically won. For positions under (a), the inclusion under (a) is immediate: we merely have to read off the position of the BK. Likewise, positions under (c) are available immediately from the tablebase *badblocked* which served us earlier in this investigation (Section 3.3).

In order to determine the set of positions coming under (b), a tablebase *runsafety* was built. Without going into details, we must note that the problem signalled in 3.3 recurred: some positions threatened to escape classification under (b) because they would, in a good strategy, alternately pursue the goals implied by (b) and (c). In its final version, *runsafety* therefore combined the characteristics of *badblocked*, of the BK being in the Troitzky zone and the h3-Pawn being blocked by a WN. Table 2 exhibits the results from *runsafety* where *n* is the number of moves needed by Black to achieve its goal, assuming mutually optimal play. Compare, though, on the validity of the notion of optimal play in these circumstances (Levy, 1988).

n	# of positions
1	39028
2	25024
3	12983
4	4915
5	1537
6	387
7	252
8	86
9	64
10	114
11	22

Table 2: Distribution of the number of positions as a function of the number of moves needed for Black to reach the Troitzky zone.

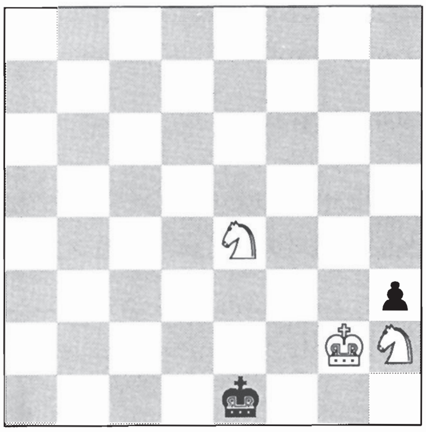

DIAGRAM 6
A maximin example leading to a draw.

From Table 2 it follows that the maximin for reaching the Troitzky zone or chasing away the blocking Knight is 11 moves. Diagram 6 shows one of the 22 maximin instances. An optimal path is 1. Kf3 Kd1 2. Ke3 Kc2 3. Kd4 Kb3 4. Kc5 Ka4 5. Kb6 Kb4 6. Nd6 Kc3 7. Kc5 Kd3 8. Kd5 Ke3 9. Ke5 Kf2 10. Ke4 Kg2 11. Ng4 h2 and White is forced to capture the Pawn, whereupon the game is drawn.

It is worth noting that Black attempts to reach the Troitzky zone as its first objective. Having been frustrated in this purpose by White's King pursuit, Black switches to the subsidiary strategy of chasing away the blocking Knight. This example is apt to show why a naive *runsafety* tablebase will not suffice.

5. STRATEGIES FOR MATE-IN-n POSITIONS

Section 4.2 presented a sample result of a strategy for Black, indicating, be it only by way of example, *how* a drawn position can be handled in such a way that it will result in an actual draw, the latter being defined as a position which is an undoubted draw to all expert observers. A much more interesting problem (and correspondingly more difficult) is to formulate a strategy for White indicating *how* to handle a *won* position (Van den Herik and Herschberg, 1986). Several approaches for the KNNKP(h) endgame have been proposed (cf. Schoo, 1988), but none of them so far has led to explicit rules-to-be-followed. This is not utterly surprising when we remember that the maximin of the won KNNKP(h) endgame is no fewer than 115 moves.

5.1. Strategies from Depth Charts?

A depth chart for an *n*-men endgame is a chess diagram showing (*n*-1) men in well-defined positions. The notion of *depth chart* is due to Roycroft (1986). The *n*-th piece is free to be located on any of the unoccupied squares. The number recorded in the square is the distance-to-mate, assuming WTM. The occasional X denotes an illegitimate placement of the missing piece. Such depth charts may serve as heuristics to discover strategies. Examples, again specializing to KNNKP(h), follow.

10	62	10	58	63	62	63	64
62	12	62	10	62	66	62	64
12	55	30	58	12	64	30	62
58	X	56	10	62	55	62	♟
10	62	X	58	12	62	55	♘
♚	12	♔	10	62	64	62	30
30	64	X	58	30	64	30	62
58	X	58	10	62	55	62	66

DIAGRAM 7
Depth chart for the h5-Pawn.

61	74	61	70	71	75	71	76
74	63	75	61	74	75	75	71
63	76	65	70	63	74	65	75
70	X	68	61	74	65	74	65
61	74	X	70	63	75	65	♟
♚	63	♔	61	75	75	74	♘
65	76	X	70	65	74	65	74
70	X	70	61	74	65	74	78

DIAGRAM 8
Depth chart for the h4-Pawn.

Diagram 7 is a depth chart with a *safely blocked* h5-Pawn, Diagram 8 similarly for the h4-Pawn. Let us consider square a4, just above the BK. The h5-chart yields the value of 10, the h4-chart shows 61. (Depth charts for h6, h7 show 9 and 10, respectively.) Clearly, there is something afoot with the pawn position, which we surmise from the dramatic increase in mating distance. To some extent this becomes explicable after placing the missing white Knight on a4. The move 1. Na4-b2 keeps the BK confined. This being so, with the *safely blocked* Pawn on h5, h6 or h7, the Knights will have little trouble in mating the BK. This is no longer true for the *safely blocked* h4-Pawn. Clearly, this relates to the number of tempi required to mate without allowing the Pawn to promote to a Queen. This is confirmed by producing an optimal winning sequence: it transpires that the BK is not mated in the a1-corner, but will have to be chased all over the board until it meets its fate in the h8-corner. We may therefore conclude that the a1-corner is far from ideal for Black given that the Pawn is located on h4. This in itself does not constitute a strategy but could be regarded as containing the germ of one.

6. TENTATIVE GENERALIZATIONS

From the blow-by-blow description of our research activity, it is readily deduced how difficult it is to verify extant statements about chess knowledge and to formulate strategies when truth down the last detail is a requirement. Finding new heuristics is even more difficult. In modesty, this has not been attempted for the moment; rather, we have made a start in developing new techniques for verifying existing heuristics, especially when these have been cast in rule form, which amounts to the construction of *tablebases*. What we *have* achieved is a generalization of *tablebase* construction, which proceeds automatically after two procedures have been suitably initialized:

- the procedure *relevant* indicating the types of positions in question;
- the procedure *goalwards* specifying the goals Black aims to achieve.

7. CONCLUSIONS

The conclusions listed below are limited in scope, having been derived from an investigation of the KNNKP(h) endgame, in which it has been attempted to formulate rules guided by an omniscient database. The finding of rules is very delicate, for which reason the research has been largely confined to testing extant rules. Applying new techniques and greatly improved hardware, the present rules have been checked for their correctness. The techniques employed are generally suitable, in our view, for the purpose of extracting knowledge from endgame databases. The results obtained are summarized in the conclusions hereafter.

1. Whenever the BP is *safely blocked* on any of h4, h5, h6, h7, the position is won for White (Section 3.5).
2. The maximin to a draw of a *not safely blocked* position is 4 moves (Section 3.4); this statement applies to blocked Pawns on any of h3, h4, h5, h6, h7.
3. The Troitzky zone as defined by Troitzky (1934) turns out to be unassailably correct (Section 4.1).
4. The maximin for reaching the Troitzky zone (hence drawing) is 11 moves (Section 4.2).
5. Depth charts only give limited indications for the strategy to be followed. While they are a potential aid in formulating strategies and classifying positions, exploiting this aid is far from easy for experts and programs alike, chiefly because it is far from clear what characteristics are important enough to be a prime consideration. Here again, the fundamental difference between knowing *that* and knowing *why* is revealed.

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