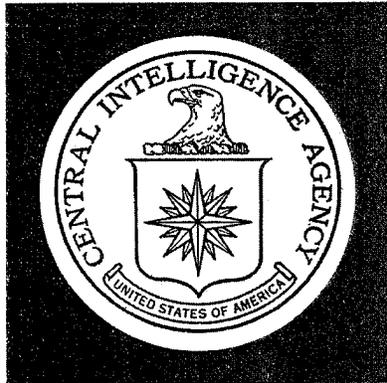


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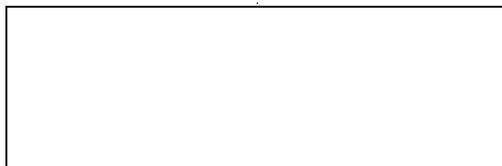
DIRECTORATE OF
INTELLIGENCE

Intelligence Report

Bayes' Theorem in the Korean War

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BAYES' THEOREM IN THE KOREAN WAR

Foreword

This report describes a test to determine the applicability of probability theory in intelligence forecasting. The test simulated intelligence estimation in 1950 on the prospect of Chinese Communist intervention in the Korean War.



Testing of the mathematical model will continue, with some shift of effort from replications of past history to "live-mode" processing of current evidence.

Replication has the advantage of a ready-made scenario complete to denouement; test participants do not mark time waiting for events to happen. However, it is difficult to replay the past in full insulation from the complicating factor of hindsight knowledge.

In any case, one approach does not exclude simultaneous work along other lines, and suggestions for future lines of investigation would be appreciated. Comments may be addressed to of the Directorate of Intelligence Planning Staff,

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BAYES' THEOREM IN THE KOREAN WAR

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Figure 1 -- Probability of Chinese Communist
Intervention in Korea: 15 September-
16 November 1950

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BAYES' THEOREM IN THE KOREAN WAR

Summary

Mathematical processing of evidence would have supported an intelligence estimate of 3 to 1 odds in mid-November 1950 that the Chinese were about to intervene in Korea on a large scale. The UN Command in Korea launched its "home by Christmas" offensive on 24 November 1950. Chinese Communist forces in unexpected strength smashed the offensive before it got really under way.

The 3 to 1 odds were reached by a mathematical simulation in 1968 that required analyst appraisals of the 1950 evidence. On the basis of these appraisals, the mathematical model applied Bayes' Theorem from probability theory to rate the comparative merits of three hypotheses about Peking's intentions--massive intervention, limited intervention, and nonintervention.

The effort was made to appraise the accumulating evidence through the eyes of the analyst in 1950. To this end, the 1968 appraisals were checked with the written record of intelligence thinking in 1950.

This kind of mental projection backward to 1950 notwithstanding, it is impossible to be sure that the 1968 simulation was entirely free from the advantage of retrospective knowledge. The indication, nevertheless, is that the massive intervention hypothesis would have scored high, whether or not the limited intervention hypothesis scored higher. The probability figures given by Bayes' Theorem would at the least have constituted a virtual directive for precautionary measures in battlefield strategy.

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I. BAYESIAN METHOD

On 25 June 1950, North Korean troops crossed the 38th Parallel to launch their surprise invasion of South Korea. US forces were quickly committed to the fighting. Would the Communists react to the US commitment by escalating their support to North Korea?

The logic for Communist introduction of non-Korean combat troops did not seem especially compelling in the first few weeks of the war. Three days after they crossed the Parallel, the North Koreans were in Seoul. The landings of the first American troops did not stop the blitzkrieg advance. By the end of July, the Americans and South Koreans had their backs against the sea, fighting in precarious defense of their Pusan perimeter at the base of the peninsula.

The chances of early North Korean victory diminished after the rapid build-up of US forces through the port of Pusan. August was a month of military stalemate; the North Koreans could not break through the perimeter.

On 15 September, American troops made the daring amphibious assault at Inchon in the North Korean rear. The expulsion of the North Koreans from the south was in sight, and American advance across the 38th Parallel in prospect.

The turn in the tide raised anew the question of Soviet and Chinese reaction. What if any limitation was there on the extent of US military success in Korea before the Chinese or Russians replied in kind? The buildup of Chinese forces in Manchuria made for especially sharp intelligence focus on Peking's intentions.

The Substitute for Certainty

A mathematical simulation of 1950 intelligence analysis on prospective Chinese intervention was conducted in early 1968. The evidence used in the simulation was only that which was available in 1950.

Mathematical processing does not conclude with yes-or-no answers. The mathematics does not eliminate uncertainty. It furnishes a basis for rational not

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infallible decision. The rational decision in situations of uncertainty is for some combination of insurance against loss and gamble for gain. The precise combination is compounded from a risk calculus which gives due weight to estimated probabilities about the future. The required intelligence support for rational decision-making is to be read not as prophecy but as a weighing of the odds, much as a gambler weighs them before placing his bets.

The Korean experience is instructive. Post-mortem criticisms took issue with the decision to advance American forces full-speed to the Yalu. Defending briefs, on the other hand, pointed to the intelligence consensus that the Chinese were not about to intervene in force.

Intelligence, for its part, might have quoted from its estimates to show that it had been far from ruling out the possibility of Chinese intervention in force.

Yet the language of the intelligence estimates may well have conveyed different shades of meaning to different readers. Suppose intelligence had supplemented its language of words with a language of numbers. Suppose it had said that the chances of large-scale Chinese intervention were less than even, but that the probability nevertheless ran as high as 40 percent or 30 percent. The matter is by no means certain, but this explicit a probability estimate could well have inclined the American command to another combination of insurance and gamble, not to the chosen strategy of swift advance to the China border by military units well in advance of their main bodies and vulnerable to entrapment.

Intelligence could offer such a numerical judgment with present methods of analysis. The 1968 simulation, however, used a model for analysis that produced a numerical judgment grounded in probability mathematics.

The problem-solving model in the simulation did better in fact than give an estimate of significant though less than even chance of Chinese intervention. Incorporating Bayes' Theorem from probability theory, the model came up with 3 to 1 odds in favor of large-scale intervention.

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The endeavor was made to incorporate all the biases of 1950 opinion into the simulation. Did the 1968 analysis free itself entirely from hindsight knowledge? It is impossible to be sure, and it therefore remains problematic that the mathematical model would have performed as well in 1950 as it did in 1968. The indication is only that the probability of Chinese intervention would have come out high enough, at the least, to constitute an injunction for careful hedge against the contingency.

The Probability Scale

Intelligence estimation under Bayesian method begins with a set of hypotheses. A starting opinion is offered about the merits of each hypothesis. This opinion is expressed as the odds or probabilities, as of a certain date, that the particular hypothesis is the true one. The starting opinion could be taken from the last National Intelligence Estimate on the subject. If so, the date of the starting odds is the date of the last NIE.

The analysis draws no further, in principle, on anyone's opinion about the hypotheses. The analysis is instead confined to examination of the evidence received after the starting date. Two judgments are made about this evidence.

One judgment rates the reliability of the reporting source or technical sensor. The reliability rating is necessary only when the accuracy of incoming reports is in question. [REDACTED]

The second judgment about the evidence rates the diagnostic value of the event reported. This diagnostic judgment is called the likelihood ratio. Would a country be more likely or less likely to follow its current propoganda line if it were going to make war than if it were going to keep the peace? The likelihood ratio states just how much more likely or less likely.

The analyst can approach his estimation of the likelihood ratio in either of two ways. One is the direct approach [REDACTED] the event reported, the analyst estimates, is say twice as likely

to happen if the war hypothesis is true than if the peace hypothesis is true.

In the second, the indirect approach, the analyst addresses himself explicitly to two probabilities. The event reported, he judges, is one that will almost certainly happen whenever the war hypothesis is true; the event otherwise has only an even-money chance of happening. Do each of these two verbal probability propositions have a reasonable numerical equivalent? If so, the first divided by the second is the likelihood ratio.

The analyst in the Korea simulation used both direct and indirect approaches. He turned the matter over in his mind one way, then the other, until he came to what he felt to be a fair judgment. He drew on the following table of equivalencies for assistance in expressing his judgments numerically.

<u>Verbal Form</u>	<u>Numerical Equivalent</u>
certainly, sure to, no question about	1.0
almost certainly	0.9
very probably	0.8
probably	0.7
on balance, somewhat more likely than not	0.6
like as not, even money	0.5
somewhat less than even chance	0.4
probably not	0.3
very probably not	0.2
almost certainly not	0.1
certainly not, impossible	0.0

Other verbal-numerical equivalencies could be defended, for there is no common standard of word usage. Some statisticians would think of "almost certainly" as a term best reserved for estimates which the analyst expected to see substantiated in 95 cases or more out of a hundred.

Whether estimated directly or by way of its component probabilities, the likelihood ratio in intelligence analysis is a personal or group opinion. The numbers in Bayesian analysis do not free intelligence from subjective judgment. They help channel subjective judgment to appraisals of evidence, letting estimative conclusions about the alternative hypotheses follow from the mathematical logic.

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Laboratory experiments at the University of Michigan and other centers suggest that this approach has advantages over traditional method. When he uses traditional method, the analyst makes one subjective leap, so to speak, to judgment about hypotheses from consideration of the evidence as an aggregate. But the analyst, these experiments suggest, has egregious imperfections as a logical aggregator. He does better when a Bayesian processor (machine or human) takes his opinions about single items of evidence and then tells him what estimative conclusion is consistent with those opinions.

The advantages and disadvantages of the Bayesian approach in intelligence analysis are still matters for research. The analyst using the Bayesian approach has his problems in estimating the probability of an event, giving the hypothesis. The analyst using traditional method has his difficulties estimating the probability that an hypothesis is true, given the events reported in his body of evidence. Perhaps the most to be said for Bayesian method in intelligence at this time is that it is one way to evaluate evidence and reach conclusions. Like the different valid ways open to a student for solving a problem in arithmetic, Bayesian method can be used as a cross-check on traditional method. When the two methods give disparate results, intelligence will want to see if the different analyses are reconcilable. On occasion, intelligence may be moved toward conclusions it would not otherwise entertain.

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II. THE KOREA SIMULATION

The analysis is assumed to begin on 15 September, when the Inchon landing turned the tables on the Communists in Korea and occasioned renewed speculation about Peking's intentions.

The Hypotheses

The first task in the exercise is the formulation of hypotheses. The main concern in 1950 was not simply whether or not Peking would get involved; the transfer of ethnic Koreans from Chinese Communist military units to the Korean armed forces had already made further military cooperation between Peking and Pyongyang seem logical enough. The key question was whether Peking would intervene with forces large enough to constitute a decisive weight in the military balance.

[redacted] therefore, which weighed only two hypotheses, the Korea simulation begins with three:

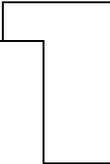
1. Chinese Communist troops will cross the Yalu in large numbers (more than 100,000) to engage in full combat on the side of the North Koreans.
2. Communist China will intervene but not with large numbers of combat troops.
3. Communist China will not intervene with its own combat troops in the Korean War.

The objective is to calculate the probability that each one of these hypotheses is true. To this end, the evidence received from 15 September on is to be examined with an eye cocked especially for what are called "indications" in strategic warning parlance. The indications may be positive or negative. That is to say, they may be signals suggestive of imminent Chinese intervention, or they may suggest Communist policy decisions against intervention.

Basis for the Starting Opinion

The task following the formulation of the three hypotheses is to estimate starting probabilities. These probabilities express the analyst's opinion about the hypotheses before his item-by-item consideration of the later evidence. This opinion is based on the impression made by evidence before 15 September and by the seeming logic of the situation. The following specific considerations enter into the analyst's estimate of starting probabilities.

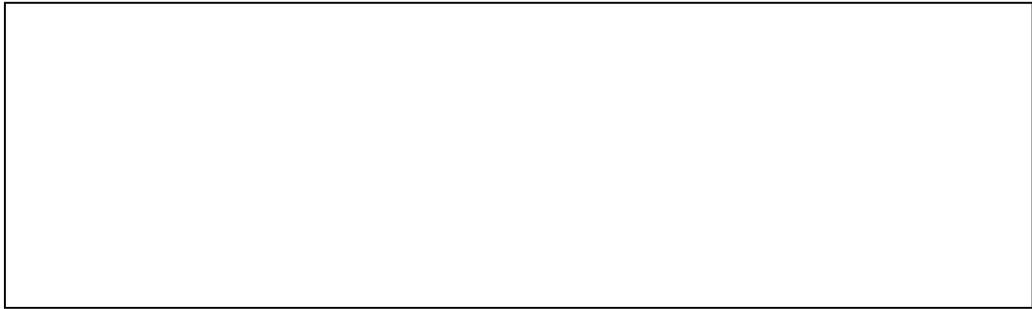
1. The Chinese Communist government in Peking is less than a year old. Communist control over the mainland is not yet consolidated; actions are still in progress against anti-Communist guerrilla forces.
2. Domestic Chinese policy gives great emphasis to economic recovery. Industrial production, agricultural output, and other economic indexes are far below their "pre-liberation" peaks.
3. Korea was a most peripheral feature of Chinese Communist foreign policy before the summer of 1950; Chinese propaganda made no mention of Korea but rather stressed the necessity of "liberating" Taiwan and Tibet. The Chinese Communists did not post their first ambassador to Pyongyang until August 1950.
4. In June 1950, Mao Tse-tung and the Central Committee of the Chinese Communist Party issued an order for partial demobilization of the armed forces. The order instructed the army to "demobilize part of its troops in 1950, but only on condition that sufficient forces to liberate Taiwan and Tibet are guaranteed as well as sufficient forces to consolidate the national defense and suppress the counter-revolutionaries."
5. The Soviet Union is treaty bound to come to the aid of Communist China if Peking is attacked by Japan or a country allied with Japan. The US is operating from bases in Japan. Chinese intervention would therefore bring the USSR closer to the brink of military confrontation with the US.

6. Peking has released to the North Korean army many troops of Korean descent who had been serving with the Chinese Communist forces. 
- 
7. Korea borders on China. Peking's apprehensions about US policy in Korea were deepened by the character of President Truman's response to the North Korean attack. The President directed the Seventh Fleet to interdict the Taiwan Strait "to prevent Communist attacks on the island and Nationalist forays against the mainland." Peking fumed at this US enlargement of the military theater as "armed aggression on Chinese territory" requiring the Chinese people to "act with firm counterblows."
8. General MacArthur's 48-hour visit to Taiwan on 1 August 1950 may also have suggested to Peking the danger of US spillover from Korea into other spheres of Chinese interest. General MacArthur again rubbed one of Peking's most sensitive nerves on 25 August, when he called Taiwan part of the island chain from which the US could "dominate with air power every Asiatic port from Vladivostok to Singapore."
9. There are recent intimations in Chinese propaganda that Peking sees its vital national interests linked to the Communist position in Korea. On 26 August, for example, the Peking radio declared that the US action in Korea "seriously threatens the security of China.... It is impossible to solve the Korean problem without the participation of its closest neighbor, China.... North Korea's defense is our defense."
10. On 17 August, the US representative in the United Nations strongly intimated the US interest in freeing the whole of the Korean peninsula from Communist control. "The Security Council has set as its first objective the end of the breach of the peace. This objective must be pursued in such a manner that no opportunity is provided

for another attempt at invasion.... The United Nations must see that the people of Korea attain complete individual and political freedom.... Shall only a part of this country be assured this freedom? I think not.... The United Nations ought to have free and unhampered access to and full freedom to travel within all parts of Korea.... We are waiting and while we wait the strength of the United Nations increases."

11. Peking responded to this statement with a cable to the US on 20 August: "Korea is China's neighbor. The Chinese people cannot but be concerned about solution of the Korean question.... It must and can be settled peacefully." Two days later, the Soviet representative in the UN warned: "Any continuation of the Korean War will lead inevitably to a widening of the conflict...."
12. While Peking has ranted at the US design to turn Korea into a "gangway of aggression" against China, there is no intimation in current propaganda that events are near the point of requiring Chinese military intervention. Peking foresees no early victory for Pyongyang but expresses faith in North Korean self-sufficiency. "...there is no doubt that the Korean people...have sufficient strength to defeat imperialist aggression and eventually to attain national liberation."
13. There are indications of plans to reconstitute the North Korean air arm with large reinforcements. Aerial photography in late August showed construction of new revetments and repair of old ones at major airfields occupied by the North Koreans.
14. US reconnaissance aircraft on missions near the Manchurian border in late August were subjected to Chinese AA fire.

15.



16. After the US Seventh Fleet interdicted the Taiwan Strait, Peking began to mute its "liberate Taiwan" propaganda. The propaganda still affirms the theme of eventual liberation, but "we must not neglect our task of national economic recovery."

17.



The Starting Probabilities

On the basis of the foregoing considerations, the analyst on 15 September estimates that Peking is clearly concerned about the potential threat to its security from the gathering US military strength in South Korea. Consolidation of domestic control and final defeat of Chiang Kai-shek, however, rate higher in the Chinese Communist scale of priorities than the expansion of Communism on the Korean peninsula. For the present at least, while US forces are as far as they are from the Manchurian border, Peking is likely to pursue a policy of watchful waiting.

The analyst feels he can almost certainly exclude imminent intervention on the scale described in hypothesis one. If the Chinese do intervene, the limited scale of intervention described in hypothesis two is probable. The chances seem better than even, however, that the Chinese will not intervene with their own combat forces at all.

Using the verbal-numerical equivalencies suggested in the tabulation on page 5, the analyst assigns .1 to the probability that hypothesis one (large-scale

intervention) is true. The starting probabilities of hypothesis two (limited intervention) and hypothesis three (nonintervention) are .3 and .6 respectively.

At this point, a moment's pause is in order for some reflections on these starting probabilities. From the perspective of 1968, it is quite apparent that the probability of the nonintervention hypothesis is not overly important. That hypothesis is going to be conclusively disproved in little more than a month. It will then be the respective probabilities of hypothesis one (massive intervention) and hypothesis two (small-scale intervention) that will be governing for the crucial US decisions about military strategy. Only these two probabilities will enter into the odds for or against large-scale Chinese intervention.

What the odds are going to be will depend on what events take place to change the odds and on what level of odds was estimated to start with. The starting odds favoring limited over large-scale intervention are 3 to 1 (the probability of hypothesis two over the probability of hypothesis one).

Will the lower starting odds of the Korea simulation unfairly bias the end result to favor the hypothesis known in hindsight to have been the true one?

This question is best answered by going back to the literature of 1950. Just what was the thinking of the intelligence community? The feeling of the community in mid-September 1950 is suggested by two authoritative analyses of the time.

One, dated 17 August observed: "As it became apparent that the North Koreans were being defeated in South Korea, the Chinese might well take up defensive positions north of the 38th Parallel. The USSR might use Chinese Communist troops at any stage in the fighting, but their participation would be especially useful at the 38th Parallel where UN members could legally discontinue their support of the US policy."

The second, published on 8 September, concluded: "In view of the momentous repercussions from such overt action (large-scale intervention)...it appears

more probable that the Chinese Communist participation in the Korean conflict will be more indirect, although significant, and will be limited to integrating into the North Korean forces 'Manchurian volunteers,' perhaps including air units as well as ground forces."

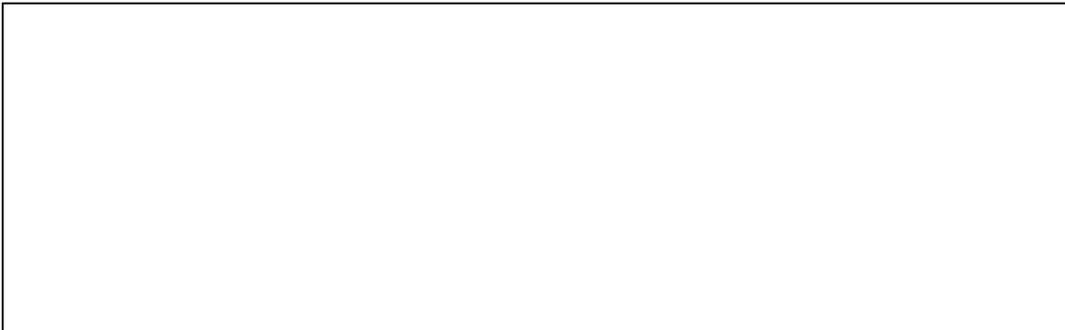
The prevailing opinion then did not reject any idea of significant Chinese troop movement right down to the 38th Parallel. Large-scale intervention was deemed to be a plausible prospect, although limited intervention was "more probable."

If the .1, .3, and .6 starting probabilities are in fact close to what intelligence felt in mid-September 1950, how should intelligence have felt later? What specific probabilities should intelligence have estimated by mid-November? On 24 November, the UN military command began its end-the-war drive to the Yalu, only to run head-on into the conclusive evidence of large-scale Chinese intervention.

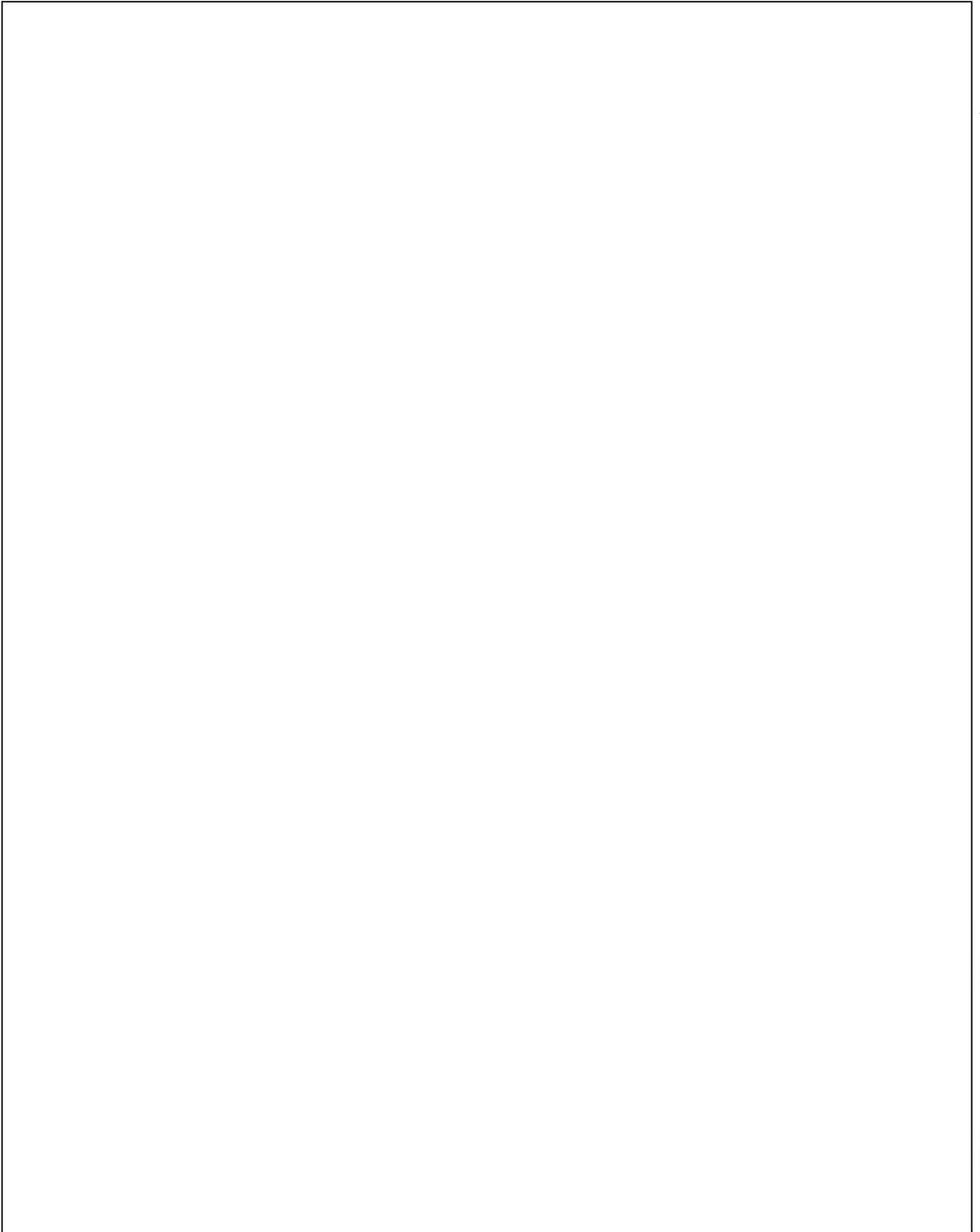
The New Evidence

These estimated probabilities of intervention and nonintervention keep changing. The warrant for change is the incoming evidence, some of it presented below to illustrate analytical method under the Bayesian approach.

Two likelihood ratios are shown for each unit of evidence appraised in September and October. The first expresses the diagnostic value of the evidence for comparing the massive intervention hypothesis with the nonintervention hypothesis. The second serves correspondingly to compare the limited intervention and non-intervention hypotheses.



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New Delhi newspapers on 4 October and 6 October carried articles with Peking datelines stating that major conflict in Korea now looked almost inevitable. The articles reported high Chinese sources as saying that when American forces crossed the 38th Parallel, they would clash with Chinese forces.



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Likelihood Ratio--1.5/1; 1.3/1

(The analyst in hindsight is tempted to assign higher diagnostic value to this unit of evidence. Intelligence thinking at the time, however, gave considerable weight to the idea the Chinese were bluffing.)

4. Success of UN Arms in North Korea--By 21 October, the North Koreans were in full retreat everywhere. UN forces had captured the Communist capital of Pyongyang.

Analysis--Peking's decision to intervene might well be contingent on the course of military events. If so, the decision to go in would almost certainly be preceded by such evidence as is now appearing, that the North Koreans cannot hold on without outside assistance.

The evidence (displaying as it does the might of US arms) could also be a deterrent to intervention. It is highly probable that the impressive military successes of the UN forces would be associated with a Chinese Communist decision in favor of nonintervention.

Both arguments are good and both considerations may be influencing Chinese policy decisions in Peking. The deterrent consideration is probably the more influential one.

Likelihood Ratio--1/1.1; 1/1.1

(The presumed deterrent effect of the UN military advance clearly influenced US analysis during October 1950. As General MacArthur put it at his meeting with President Truman in mid-October on Wake Island: "Had they interfered in the first or second months, it would have been decisive. Now we are no longer hat in hand... if the Chinese tried to get down to Pyongyang, there would be great slaughter." The consensus of the intelligence community in mid-October also was that the time for effective Chinese Communist intervention had probably passed.)

The first contacts with Chinese troops toward the end of October eliminated the nonintervention hypothesis from further consideration. Only one likelihood ratio is therefore shown after October. This likelihood ratio describes the diagnostic value of the evidence for comparing the massive intervention hypothesis with the limited intervention hypothesis. Where accuracy of evidence is in question, a reliability rating is also assigned.

5. War Propaganda After the Initial Intervention--Peking propaganda on the war, which had diminished just before the entry of Chinese troops into Korea, stepped up again after the intervention.

On 31 October, People's Daily declared in an editorial: "The ambitions of the US imperialist bandits will not be satisfied with the attack on Korea. Truman will certainly extend his aggressive war to the borders of China...following in the footsteps of the Japanese predecessors who also began with aggression against Korea and then the Northeast and the interior of China. But this aggression will not be tolerated by the Chinese people."

Excerpts from other propaganda at this time follow:

"The war in Korea has now entered a new phase.... China and Korea are separated by one river, with the two countries having over 1,000 li of common front...."

The Korean people "took an active part in China's revolutions and did not hesitate to shed their blood and sacrifice themselves for our cause."
(FBIS noted a sharp increase during the first week of November in propaganda to convince Chinese domestic audiences that they owed a "blood debt" to Korea.)

"It is very clear now that American imperialism is following the beaten path of Japanese imperialism --the wishful thinking of annexing Korea, and then from there invading our Northeast.... The Chinese people will not tolerate a repetition of the history of 45 years ago. Therefore we must be on the same front as the Korean people.... Rise up in the struggle against the American imperialist aggressors to aid our heroic Korean brethren."

During the closing week of October and early November, mass rallies were held in every major Chinese city. The rallies staged pledges to defend the fatherland by "volunteers anxious to fight the American imperialists in Korea."

"Resist America, Aid Korea" was the slogan of the propaganda campaign, but the propaganda was not explicit about the scale of intervention envisaged. It was intimated in one Chinese Communist article, however that the intervention should be massive enough to bog the Americans down in Korea: "There are two possibilities.... One is that the American imperialists will be forced off the Korean peninsula.... The second is that after US troops suffer defeat, they will continue to increase reinforcements, ceaselessly expending men and material, becoming mired ever deeper and more helplessly."



Analysis--The Chinese would almost certainly mobilize domestic opinion in this fashion (.9 probability) if they anticipated fighting in force against the US. However, there are enough ambiguities in the propaganda to leave the Chinese the option of support to the Koreans in a campaign of guerilla resistance. The chances are better than even (.6 probability) that aid to North Korea in the form of overt guerrilla support would be preceded by the same propaganda line as would precede all-out intervention.

Likelihood Ratio--1.5/1

6. Improved Communist Military Capabilities--There were signs in early November that Chinese participation contributed markedly to the stiffening of Communist military resistance.

Chinese units were evidently in close proximity to the regrouped North Koreans. One North Korean military document of 6 November mentioned a

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meeting with the "division commander of the 55th Force of the Chinese People's Liberation Army." Other North Korean military documents referred to the "volunteer army."

[REDACTED]
[REDACTED] Captured Chinese prisoners reported that the entire 38th Army (20-30,000 men) had crossed the Yalu on 24 October.

An increase in air capabilities was also observed. MIG aircraft engaged by US pilots flew in from the Chinese side of the Yalu. They had no markings on wings or fuselage.



Analysis--The Chinese ground troops so far known by US intelligence to be in Korea number fewer than the 100,000 postulated in the all-out intervention hypothesis.

However, the reference to "division commander" is noteworthy.

This reference and the evidence (as yet unconfirmed) of an entire army crossing the Yalu suggest that large Chinese military units are perhaps being kept intact--that forces are not being infiltrated in mere battalion or other small-unit strength for say support of guerrilla operations.

The signs are almost certainly (.9 probability) of the kind that would now be appearing if all-out intervention is imminent. The signs are

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also compatible, however, (.6 probability) with a probing effort that the Chinese will abort when the US demonstrates its clear superiority on the battlefield or threatens to carry the war to Chinese territory.

Likelihood Ratio--1.5/1

Reliability Rating--.7

(Intelligence opinion at the time took a grave view of this evidence. The JIIC [Joint Indications Intelligence Committee, predecessor of the USIB Watch Committee] noted on 8 November that "elements" of four Chinese armies had been identified in Korea and that the estimated number of troops in these elements was 30,000. But "from the successes achieved by the North Koreans with Chinese assistance in their counter-offensive in Northwest Korea, it is difficult to believe that considerable more Chinese or North Koreans trained in China are not employed. If the full four Chinese armies are engaged, then the figure will be in the neighborhood of 100-200,000. Reports from the American units engaged describe the enemy as the best so far encountered in Korea. They are described as being more vigorous, skilled and better coordinated in night movement and attack.")

The Revised Opinion

The impact of these and the other units of evidence on the odds is shown graphically in Figure 1. The weight of evidence does not really begin to tell in favor of the massive intervention hypothesis until the first brushes with Chinese troops rule out the nonintervention hypothesis at the end of October. These first contacts with the Chinese bring the probability of massive intervention to 30 percent. The probability rises thereafter until it stands at over 75 percent in mid-November.

Only a week before, the intelligence analyst in the simulation would have estimated about an even-money chance of large-scale intervention. The simulation is an instructive lesson on the transient value of the intelligence estimate in the crisis situation, on the imperative in such a situation of keeping intelligence opinion unfrozen, on the necessity during the crisis of staying receptive to every new item of evidence, on the obligation to revise the odds from day to day or hour to hour.

With the probability value at about 75 percent, the intelligence analyst in the simulation can use his table of verbal-numerical equivalencies (page 5) to say that large-scale intervention is probable. He can say this much verbally and numerically and unequivocally. He would want to supplement his unequivocal statement of the probabilities with the kind of well-reasoned estimative conclusion that features good intelligence writing today. The hindsight critics notwithstanding, it was the mark of good intelligence in November 1950 also. Three examples from the period follow.

The first is from NIE-2 of 8 November 1950: "The Chinese Communists...are free to adjust their action in accordance with the development of the situation. If the Chinese Communists were to succeed in destroying the effective strength of UN forces in northern Korea, they would pursue their advantage as far as possible. If the military situation is stabilized, they may well consider that, with advantageous terrain and the onset of winter, their forces now in Korea are sufficient to accomplish their immediate purposes.... A likely and logical development of the present situation is that the opposing sides will build up their combat power in successive increments to checkmate the other until forces of major magnitude are involved."

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The second is from the conclusion of the Joint Indications Intelligence Committee (predecessor of the USIB Watch Committee) after its meeting on 15 November. There was a definite possibility, the Committee noted, of major Chinese Communist intervention in Korea. Chinese strategy, the Committee report continued, seemed designed to halt the UN advance in Korea and to stall for time while preparations for larger action were completed.

The third is the 24 November update of NIE-2. (This was the date the UN offensive drive to the Yalu began; the NIE is based on information as of 21 November.) Chinese military activity so far, observed the estimate, does not demonstrate any plan for major offensive operations. However, if Peking fails to obtain UN withdrawal from Korea by intimidation and diplomatic means, there will be increasing Chinese Communist intervention.

Nobody hit the nail right on the head, but the analysis in retrospect does not look bad. Somehow the verbalizations did not communicate the full measure of intelligence anxiety to the political and military commands. Bayesian method in intelligence is an endeavor to go beyond the necessary verbalizations. Its objective is valid quantification of probabilistic judgments. Its ideal is the union of phrasemaking with unambiguous numerical scoring, so that uncertain information can make its due contribution to rational decision.

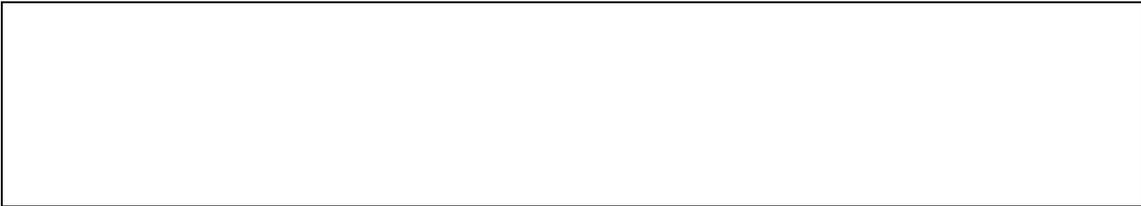
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TECHNICAL NOTES

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A. Basic Bayes



The formulation of hypotheses was different in the Korea simulation; they were propositions in the future tense. Communist China will intervene in the Korean War with large forces, it will intervene with small forces, or it will not intervene at all.

There was no assumption in the Korea simulation that the incoming evidence was necessarily derivative of Chinese policy decisions already taken to intervene or not to intervene. The reasoning was simply that certain events are more likely (or less likely) to precede intervention than nonintervention.

Whether the hypotheses are cast in past or present or future tense, the mathematics is straightforward. Let an hypothesis be stated in the future tense: war will break out.

Now let $\text{Prob}(eW)$ stand for the probability that event e will occur first and that war will break out soon thereafter. This probability is equal to the product of two factors. One is the probability, represented by $\text{Prob}(e)$, that event e will occur whether or not war follows.

The other factor is $\text{Prob}(W|e)$ --read "given" for the vertical stroke symbol. $\text{Prob}(W|e)$ is the probability that war will break out, given that event e has already occurred.

In concise mathematical formulation, the probability logic can then be written as:

$$\text{Prob}(eW) = \text{Prob}(e) \times \text{Prob}(W|e)$$

Alternatively, $\text{Prob}(eW)$ may be expressed as a product of two other factors. Before anything is known or assumed about event e , what is the probability that war will break out? This probability, represented by

Prob(W), is one factor. Given that war will break out, what is the probability that it will be preceded by event e? This probability, represented by Prob(e|W), is the second factor. So,

$$\text{Prob}(eW) = \text{Prob}(W) \times \text{Prob}(e|W)$$

These two equations establish a third:

$$\text{Prob}(e) \times \text{Prob}(W|e) = \text{Prob}(W) \times \text{Prob}(e|W)$$

Divide both sides of this third equation by Prob(e). The result is one form of Bayes' Theorem:

$$\text{Prob}(W|e) = \text{Prob}(W) \times \frac{\text{Prob}(e|W)}{\text{Prob}(e)}$$

In mathematical parlance, Prob(W|e) is called the posterior probability of war--the probability in the light of the latest evidence. Prob(W) is the prior probability of war--the probability estimated before the latest evidence was received.

Similar notation can serve to show the probability that no-war hypothesis N is the true one. That is,

$$\text{Prob}(N|e) = \text{Prob}(N) \times \frac{\text{Prob}(e|N)}{\text{Prob}(e)}$$

Suppose the task to be the determination of odds favoring the war hypothesis over the no-war hypothesis. These odds simply set the probability of war over the probability that the no-war hypothesis is true. The result is the following equation:

$$\frac{\text{Prob}(W|e)}{\text{Prob}(N|e)} = \frac{\text{Prob}(W)}{\text{Prob}(N)} \times \frac{\text{Prob}(e|W)}{\text{Prob}(e|N)}$$

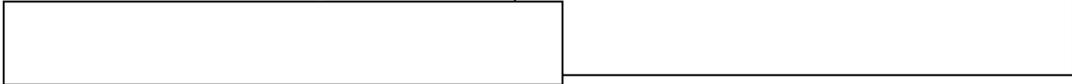
Simplify the notation by substituting one symbol for each fraction in this equation. If the notation used in the Cuba study is borrowed, the equation then reads:

$$R = PL$$

R stands for the revised or posterior odds favoring the war hypothesis over the no-war hypothesis. These are the odds after consideration of the latest evidence. P, the prior odds, is carried forward from consideration

of the previous evidence. If accuracy of evidence is not in question, the main burden on the analyst is to decide on the value of L, the so-called likelihood ratio.

If accuracy of evidence is in question, he is under the additional burden of rating the reliability of the reporting source.



The intelligence analyst applying Bayes' Theorem does not keep debating with himself or with others the merits of the hypotheses. Approaching the evidence in the Korea simulation, he does not ask how each new event affects his own or anybody else's previous estimate about prospective Chinese intervention in the Korean War.

He asks himself, instead, how likely the event would be, given that say the massive intervention hypothesis is true. He asks himself also how likely the event would be if the nonintervention hypothesis is taken as true. His answers to these two questions give him the probability components of L, the likelihood ratio.

Or, estimating the likelihood ratio directly, he combines the two questions and asks himself how much more likely the event would be if one hypothesis is true than if the other is true. But he does not ask himself how the event affects the probability that an hypothesis is true. He inverts the question to ask how probable would the event be under the assumption that the hypothesis is true.

B. The Partitioning Problem

The mathematics of Bayes' Theorem was illustrated in the [] by the poker chip experiment. The experiment typically involves two boxes containing red and blue poker chips in different proportions. The color mix is say 60-40 red-blue in the so-called war box, 40-60 red-blue in the no-war box.

A test subject is given this information, but he cannot tell the boxes apart from their outward appearances. He picks one of the boxes at random from the shelf. His task is the determination of the odds favoring the war hypothesis (that he has picked the war box) over the no-war hypothesis.

In the beginning, he can give no better than even-money odds. That is to say, he starts with a value of 1/1 for P in his Bayesian equation $R = PL$. Then, drawing chips at random from the box in front of him, the test subject applies his likelihood ratios to send the odds up or down.

Suppose the test subject replaces each chip after noting its color. The latest event is the draw of a red chip.

The value of L is determined by the formula:

$$L = \frac{\text{Prob}(e|W)}{\text{Prob}(e|N)}$$

The numerator is the probability of drawing a red chip (.6), given the condition that it is drawn from the war box. The denominator is the probability of drawing a red chip (.4), given that it is drawn from the no-war box. The likelihood ratio for this event, the draw of a red chip, is thus 3/2.

The only conditions the analyst considers when evaluating the event are these "given war" and "given no-war" conditions. The previous evidence, once it has been incorporated into his odds, is not considered again. The reason it is not considered again is that each chip drawn from the box is replaced before another is drawn. Thus the probability of getting a red or blue chip from the war box or no-war box never changes; the probability is not affected by the previous evidence.

Suppose each chip drawn is not replaced. Then the probability of drawing a red chip or blue chip from a specified box does not stay the same throughout the experiment. The probability is determined, not only by the condition that the chip is drawn from the specified box, but also by the number of chips and combination of colors previously drawn. The value of L may then be expressed as:

$$L = \frac{\text{Prob}(e|WE)}{\text{Prob}(e|NE)}$$

The numerator again has the vertical stroke to indicate that the probability holds only if a certain condition is taken as given. The condition now is, not only as before that the red chip is drawn from the war box, but also all the previous evidence (denoted by the symbol E). The denominator similarly is a probability which this time depends, not only on the hypothesis assumed true, but also on the previous pattern of evidence.

The analyst appraising each new unit of evidence in the Korean simulation generally took only hypotheses as given, not previous evidence. In other words, the probability of a unit of evidence was generally held to be no different for appearing in November than in October or September.

The instinct of the intelligence analyst is to recoil from this supposition. Intelligence doctrine makes much about the significance of patterns. Military deployments officially described as training exercises, for example, take on more significance if preceded by ominous evidence than if preceded by reassuring evidence. Is a unit of evidence in Bayesian analysis to be given the same likelihood ratio--to have the same effect on the odds for war or peace--no matter what the surrounding context of other evidence?

The answer requires a clarification of terms. The necessary distinction to make, an important one in probability theory, is between conditional independence and unconditional independence.

Once again the poker chip experiment helps to clarify the issue. The test subject can give no better than even money that the first chip he draws will be

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red. But if he draws (with replacement) a series of 100 chips, of which 58 turn out to be red, he can estimate something close to a .6 probability that his next draw will be red. The mathematician would call the events unconditionally dependent--unconditionally because nothing is postulated about the box the test subject is drawing from, dependent because the probability of drawing a red chip changes as the pattern of previous evidence becomes more conclusive.

He would also say the events are conditionally independent. Given the condition that the test subject is drawing (with replacement) from a specified box, the probability of drawing a red chip never changes, that is, never depends on the pattern of previous evidence.

Selection of hypotheses, in other words, makes it possible to treat many events as independent of the previous evidence. The intelligence analyst says, "of course they are dependent," and in one sense, he is right. But if he is applying Bayesian method, he has to know the sense of the word he is using.

If he is applying Bayesian method, one of the burdens on him is the partitioning of evidence to get, as far as possible, counterparts of poker chip drawings with replacement. In practice, it is a problem of avoiding serious error rather than escaping error altogether, for judgments about correct partitioning will vary from person to person.

The rule of reason is to combine all reports on one general subject into one unit of evidence. The analyst with a little training in probability theory may well do better at partitioning than the one relying only on his sense of practical reason. The analyst with some theoretical background may also do better at recognizing the cases where, despite his best efforts, he is left with some conditionally dependent units of evidence. When such cases arise (as they inevitably do), he must estimate his likelihood ratio accordingly. Does Chinese propaganda contain a note of dire warning which was also observed in a preceding unit of evidence? The propaganda will not be appraised as it would be if it stood alone.

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C. Bayes and Bias

Every hypothesis is diffuse; it covers more ground than is explicit in the wording. To make the hypothesis more explicit, substitute subhypotheses.

The nonintervention hypothesis, for example, can become two subhypotheses that incorporate alternative propositions about Chinese defensive policy. One non-intervention subhypothesis is that Peking will not intervene but will build up its defenses in Manchuria. The other nonintervention subhypothesis is that Peking will neither intervene nor improve its defensive capabilities in Manchuria.

The number of conceivable subhypotheses is myriad. Fortunately they do not all have to be introduced into the analysis. Nor once introduced, do they have to be considered in the appraisal of every unit of evidence. A subhypothesis about defensive buildup may be important when weighing evidence about troop deployments. A subhypothesis about hedging against pound devaluation may be important when weighing evidence about drawdown of sterling deposits.

A distinguishing mark of the professional in intelligence analysis is his ability to explain evidence--and sometimes to explain it away--by introducing subhypotheses. When he explains evidence away, it is by rejecting one of his alternative subhypotheses. In the Korea simulation, the possibility of nonintervention without a defensive buildup in Manchuria was rejected as altogether implausible. The Chinese might not intervene, so the feeling went, but they would surely hasten to improve their defensive capabilities in Manchuria.

Given this judgment, the evidence on troop movements to Manchuria did not give intelligence much of a bearing on Peking's intervention intentions. Until troop redeployments reached a scale that suggested a buildup past the needs of simple defense, the evidence carried a 1/1 likelihood ratio.

Suppose intelligence felt that Chinese nonintervention would very probably (.8) but not certainly entail a policy of defensive buildup in Manchuria. As before, troop

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deployments toward Manchuria would be evaluated as necessary and certain if Peking were about to intervene; they would be equally necessary and certain if Peking were not intervening but implementing a policy of defensive buildup in Manchuria.

However, to complete the chain of reasoning, intelligence would now also have to bring in another opinion about the probability of troop movements to Manchuria-- the probability if Peking were not intervening and had no policy of defensive buildup. The intelligence opinion would be influenced by the knowledge that Lin Piao's Fourth Field Army was slated in any case to return to its home base in Manchuria after the Communist conquest of the Chinese mainland. Suppose therefore that intelligence felt there was an even chance (.5) of these northward troop movements in September even if Peking were not intent on improving its Manchurian defenses.

The Mathematical Notes, Topic D, of the present a formula for calculating the likelihood ratio when subhypotheses are introduced in this fashion into the analysis. Under this formula, the suppositions given above would have resulted in a 1.2/1 likelihood ratio for the early evidence about troop movements to Manchuria, not the 1/1 ratio that was in fact assigned.

The undiagnostic 1/1 likelihood ratio was applied in the simulation because the intelligence analyst felt so strongly about his subhypotheses. Bayes' Theorem does not eliminate strong feelings. If he is reasoning toward probabilistic conclusions, the analyst will find Bayes' Theorem an especially useful rule of logic. Like all other rules of formal logic, it makes the most of antecedent propositions by assuring conclusions that are consistent with those propositions. But it does not free analysis from prepossession and predilection.

Figure 1

PROBABILITY OF CHINESE COMMUNIST INTERVENTION IN KOREA 15 September - 16 November 1950

