concrete incorporated in the busway construction. The engineer recognized that concrete could be subject to problems attributable to the aggregate available in the Pittsburgh area. These aggregate, generally obtained by dredging the rivers or mining bank deposits, contain soft particles, coated pieces, or other troublesome materials.

In the design stage, the engineer selected concrete strengths to be specified that were within the experience record of the local concrete industry. Furthermore, a testing program was developed and incorporated into the specifications that would ensure that the aggregates used would be properly monitored in order to provide the necessary concrete strengths.

During the prebid stage, the engineer reviewed the specifications and required testing program with the local concrete suppliers and potential bidders. Discussions were held and the objectives behind these requirements were explained to the industry.

After the award of the contracts, the engineer met with the successful bidders, their appointed testing laboratories, and their concrete suppliers and assisted in the preparation of the quality-control manual for concrete. As concrete was supplied to the job, the results of the quality-control program were monitored and adjustments were made.

Throughout this procedure, the engineer assumed a leadership role, through the coordination of the efforts of the other team members. Through definition of objections, persuasion, and open discussions, the contractors and their suppliers were convinced that the program was to their advantage as well as to the advantage of the owner. The result of this effort is that the East Busway construction has proceeded without any concrete being removed because of insufficient strength.

CONCLUSION

Contractual relationships are an essential ingredient of the quality-assurance programs of all construction projects. Responsibilities and obligations must be clearly defined by contracts and the team members must undertake the fulfillment of these responsibilities. However, the success of the project is dependent on the team members' performance and interrelationships with the other team members. All the team members must function in this area, but the engineer, because of this understanding of the work, has the opportunity to develop the relationship necessary for success.

Contractor's Viewpoint and Case Study of Pittsburgh's $27 Million South Busway Program

JOHN C. MASCARO

Project participants on Pittsburgh's new South Busway worked hard to create a productive climate for the successful completion of their $27 million busway program. Throughout this project, quality assurance was of paramount importance. Quality construction and a productive climate were compatible through cooperation, goodwill, mutual trust, and teamwork among the owner, consulting engineer, contractor, and other parties. The project was completed on time and within budget through the owner's willingness to assume a fair share of risk. The principles and philosophies illustrated by this case study are not new and were used with a common-sense approach to the successful completion of this project.

This paper presents a case study of the contractual relationships among owner, engineer, and contractor on Pittsburgh's South Busway Program and their effect on quality assurance. For the purposes of this paper, the following definitions are applicable:

1. Quality assurance is the total system that is used by management, their engineers, and their consultants to answer the general question, Are we doing the right things?
2. Quality control is that control that a person undertakes to check in a systematic manner, that the steps for implementation are correct and will enable the project to be constructed in the specified way.

The owner of the project was the Port Authority of Allegheny County, the engineer was Michael Baker, Jr., and the contractor was Cameron Construction Company, a Pittsburgh-based construction engineering and management firm.

Although traditional contractual relations among owner, engineer, and contractor were employed, a productive climate was created through cooperation, goodwill, mutual trust, and respect. More importantly, the project was completed on time, within budget, and with quality construction.

TRADITIONAL APPROACH TO THE CONSTRUCTION PROCESS

The owner's need to build usually results in a construction project. Owners are individuals, companies, or governments that must satisfy physical needs. Construction projects are physical needs and might be in the form of a home for a family, a large office building for a corporation's headquarters, or a new highway or dam for the federal government.

Once an owner decides to build, an engineer or architect is hired to evaluate the owner's needs. Throughout this paper, engineer, architect, and designer will be used interchangeably and synonymously. They shall represent a person, company, or group of partners that provides feasibility studies and conceptual designs based on the owner's scope parameters and budget. This is the first phase in the traditional construction approach and is called the decision phase. Once these initial items are completed, the owner then hires an architect or engineer to finalize the overall design and to make the drawings and specifications. This is the second phase, called the design phase, in which the architect or engineer develops a solution to meet the owner's requirements. These solutions are evidenced by plans and specifications and are referred to as the contract documents.

The third phase is the bid phase, which can follow two possible paths. If the owner intends to follow the competitive bid process, contract documents are issued to general contractors interested in bidding. The list of general contractors who bid can be a general list of qualified contractors or a select list of qualified contractors. The contractors then review the contract documents and submit their prices for the project to the owner for consideration. The owner then reviews the bids and makes the award of the contract. If the owner is a public agency, it is usually mandated to select the lowest responsible bidder; private owners may choose this or other criteria for selection.

The fourth phase is construction. Here the owner usually hires the architect or engineer to inspect and supervise the work performed by the general contractor and subcontractors. If during this phase the owner or architect or engineer decides to change the scope of work or the contract documents, they negotiate with the contractor to determine a fair price for the proposed changes. Figure 1 illustrates this traditional approach.

It is beyond the scope of this paper to discuss the advantages and disadvantages of the various contractual relations between the owner, architect, or engineer, and contractor. There are several other contractual relations that currently exist, such as design-build or turnkey contracts, construction-management contracts, owner as the construction manager with several prime contracts, engineer as the contractor and construction manager, plus other various combinations (1). Each one may have a different effect on quality assurance.

This traditional approach normally precipitates adversary roles among the owner, engineer, and contractor. The adversary relationship can and must be eliminated at all costs.

The South Busway was a $27 million project that was completed to everyone's satisfaction without litigation. The busway project did not have any special contractual relations with imaginative management and quality-assurance gimmicks. The owner, acting largely through the engineer, set out to foster a climate of cooperation. Foremost in the owner's mind was the main goal: to build the highest-quality project for the least cost.

BASIC ATTITUDE OF CONTRACTOR

The exact role of the contractor cannot be defined until the low bid is submitted and the owner and engineer have a chance to evaluate the contractor's attitude toward the project and quality assurance. The owner and engineer determine the projected course of action for the contractor. The contractor responds to the way he or she is treated. The Port Authority of Allegheny County and Michael Baker, Jr., Inc., created a productive construction environment in which the busway was to be built. Their attitude and construction values were analogous to ours. They were committed to a team-concept approach, where everyone worked together toward the same end product. Cameron Construction Company was not an adversary, and profit was not a dirty word. An open line of communication was immediately established between the Port Authority, Michael Baker, Jr., and Cameron Construction Company.

OWNER'S ROLE IN THE TOTAL SYSTEMS APPROACH

The total systems approach for quality assurance must use the team approach. At the beginning of any project, mutual trust, respect, and confidence must be established immediately among the team players. A thorough understanding of the main objectives and roles of each player is important to the success of the project. Adversary relations among the owner, engineer, and contractor must be eliminated and open communications among all parties will lead to resolution of issues with a cooperative approach within the framework of the contract documents. Communication was maintained via biweekly meetings held at the job site.

Another effect on quality assurance, besides the contractual relation among owner, engineer, and contractor, is the method of procurement for construction services. It should be analyzed and reevaluated. Lester Fettig, chief of the Office of Federal Procurement Policy, is strongly against the federal government's policy that "price is all". He asserted, "Taking the low bid is not a sensible way to buy anything, not even toothpaste". Sometimes the low bid is not always the cheapest for the owner. A contractor who has haphazardly prepared a low bid will be in trouble if he or she has not effectively considered all of the problems in a project. If a poor bid has been made, the contractor will realize, after construction is under way, that actual costs are substantially greater than estimated costs. If this disparity is large enough and the contractor cannot afford the loss, bankruptcy will result. Thus, completion of the project is delayed until another contractor can be solicited to complete the job. Delay costs everyone money.

Regardless of the method of procurement used by the owner, it is necessary that a productive management strategy be established that

1. Involves team players in reaching mutually agreed on goals and objectives,
2. Shares risk equitably, and
3. Encourages mutural respect, trust, and confidence among the owner, engineer, and contractor.

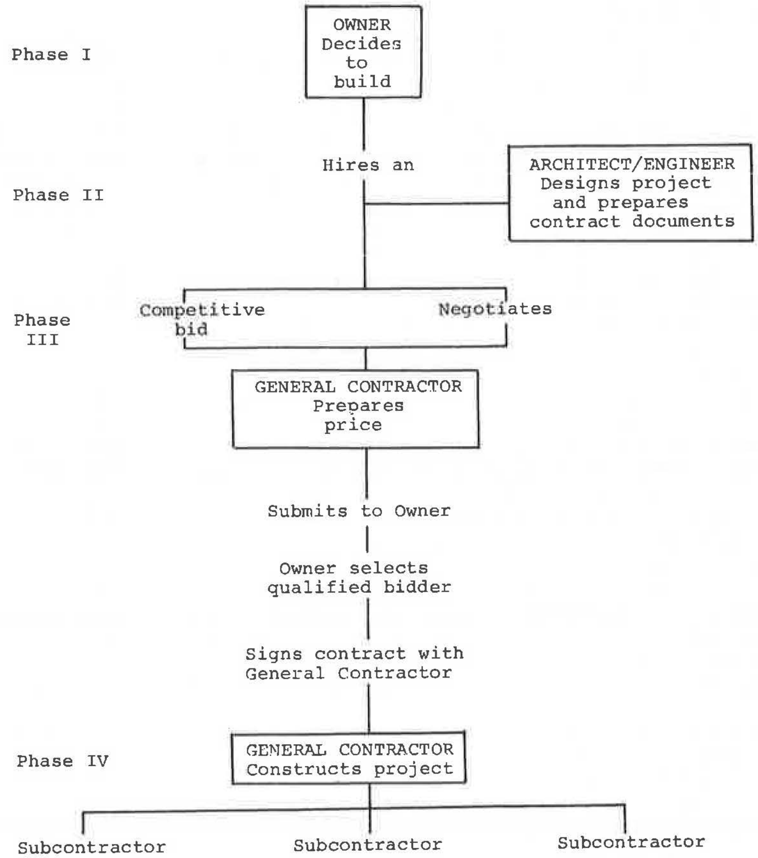
TOTAL SYSTEMS APPROACH

The exact role the engineer plays in the quality-assurance program is determined directly by the owner. The nature of contractual relations between the owner and engineer determines the involvement of the engineer during the construction phase. The owner may procure the engineer's services via competitive bidding or may negotiate with the engineer. If bidding for professional services is required, the engineer will be forced to use standard specifications and designs used previously on other projects to keep the cost down. Little time will be spent for the particular project. Inappropriate designs and specifications will lead to delays in the field and thus cause decreased productivity. If the engineer has the luxury of a negotiated contract with the owner, he or she can afford the time to guarantee that specifications are not obsolete and that the designs are economically constructible. Productivity begins long before the job starts and, once construction starts, the additional money spent in the initial stages of design will pay for itself many times over.

The majority of suggestions listed are based on the premises that (a) the contractor must bid competitively on the project; (b) the owner is public, not private, and does not do his or her own design; and (c) the engineer is a separate entity and has responsibility for design and inspection of construction but does not do the construction. Obviously there are many combinations of relations among the owner, engineer, and contractor. Some owners may want a design or build service from a firm where the contractor does the design and construction.

The traditional role for the owner, engineer, and contractor will be assumed. Resulting suggestions

Figure 1. Traditional approach to the construction process.



for improving quality assurance will be germane regardless of what type of construction method is employed.

The engineer's role in quality assurance will be analyzed in the following areas:

1. Working environment,
2. Specifications and design,
3. On-site inspection,
4. Risk sharing, and
5. Delays and changes.

Working Environment

Perhaps the most important role the engineer can play is that of team captain. The team consists of the owner, engineer, and contractor associated together in the construction of a project. The players are bound together by their contractual obligations and responsibilities, and the successful completion of the project is their ultimate goal. It is paramount that a constructive, working environment be established at the onset of the project. The engineer should share in the coordination and creation of a cooperative atmosphere. Everyone must recognize and respect the other's job and responsibilities. The success of the job depends on the cooperative attitude of the other participants. A good working environment will provide quality construction; a poor one creates confusion and disaster.

Specifications and Design

The plans and specifications are the framework within which the project is to be constructed. The language of the specifications has certain connotations that can create a good or bad working environment. Some examples of these contract provisions are given in Table 1 (2).

The tone and language of the specifications project the engineer's attitude about the project. Every specification has a price tag. The more devious is the language of the specification, the greater is the cost of the project to the owner. Language must be clear, firm, concise, and direct to ensure a quality product.

The specifications committee of the American Society of Civil Engineers (ASCE) conducted a survey to better understand the differences between the engineer and contractor regarding specifications. The results, published by Fisk, indicated that specifications are usually poorly written, ambiguous, obsolete, unclear, and irrelevant (3). Specifications are being prepared by writers who do not fully understand the complexity nor the importance of the document they prepare. Specification writers should be professionals who have field experience and can write with clarity and directness. Exculpatory clauses should be eliminated.

The apparent solution, according to Fisk, is to specify by objectives. "Specifying by objectives is little more than a new title for common-sense specifying." Under this concept, the specifications are written to meet only the specific needs of the project. This differs from the traditional approach only in that predetermined, arbitrary standards are avoided as long as the meaningful, true objectives can be reached successfully without them. In short, it means the following:

1. Determine the objectives (functional, quality);
2. Meet the objectives (allow reasonable tolerances);

Table 1. Evaluation of contract provisions.

Contract Provision	Good	Bad
Mobilization	Pay item for mobilization to compensate contractor for costs of mobilization and construction plant	No pay item for mobilization; contractor must unbalance bid or bank this cost until sufficient progress payments will cover them
Assignment of risk	Owner takes risk not controllable by the contractor, such as escalation, furnishing of long lead items, pay items for unknown but possible problems such as handling of ground water	Contractor takes all risks, including problems not under own control; as a consequence, must put contingency in bid that may be either unused or insufficient
Labor agreement	Area or project agreement negotiated in advance to set job rules, set up means of quickly settling disputes and means of arbitration	No agreement; contractors asked to take complete risk; negotiate job rules after award of contract
Right-of-way, contractor's work areas and permits	Owner obtains all right-of-way and work areas as well as all necessary permits in advance of construction	Contractor left to obtain right-of-way, work areas, and permits with insufficient time and no leverage
Schedule	Realistic schedule with time contingency included for expected delays and extension of time provisions to cover delays beyond contractor's control	Unrealistic schedule requiring shift work and extended workweek to complete on time with no provision for time extensions; contractor will consider these effects and add costs for these requirements

3. Do not exceed the requirements of the objectives.

Unrealistic or unnecessary constraints are costly. The owner must pay the bill.

The contractor's responses to the committee questionnaire on specifications have pointed out the need for improvement by many design professionals and have given birth to the concept of specification by objectives. If this concept is applied intelligently, by using properly qualified specifications engineers (not just specifications writers), it will be the first step in improving the turmoil that exists between the contractors and the specifiers. It seems a small wonder that the contractors' license board in California lists the failure to follow plans and specifications as the principal cause for the majority of contractor license suspensions.

On-Site Inspection

Too often the specifications are considered the bible and are blindly enforced by the on-site inspectors. Inspectors should use the specifications as a guideline only and good common sense should govern all decisions. The inspector should tell the contractor only what has to be done, not how to do it. Quality control and field testing should be placed on the contractor, not the engineer or owner. To safeguard the public's interest and ensure quality, a maintenance bond for a specified period can be provided by the contractor. This will guarantee end result and performance of the finished product. The contractor should have an independent testing laboratory to perform specified tests, in accordance with contract documents. The role of the inspector is elevated to that of a problem solver and not of a policeman or note taker. The inspector should have the authority to make decisions and not have to worry about being second guessed. The inspector should have the competence and knowledge to handle all job-related problems. If the engineer's inspection staff is multilayered, this layer of personnel will find it necessary to make their jobs important and have a tendency to cause delays in the field by questioning the contractor's operations to the nth degree.

In summary, if objective or performance specifications are used, the inspector only has to worry about the end product that is created by the contractor. The inspection staff should be small and well paid, use specifications as a guideline not a bible, and have the authority, competence, and experience to make all job decisions. Most important, the inspectors should have the right attitude and treat the contractor like a teammate not an adversary. Finally, profit should not be a dirty word in the inspector's vocabulary. Additional aspects concerning construction inspection not covered here are given in the ASCE task committee report on inspection (4).

Risk Sharing

Often too many exculpatory clauses are included in the contract documents. The engineer uses these clauses to cover for potential errors and omissions. Everyone should be willing to accept a share of the risk. There is no such thing as a get-something-for-nothing or at-no-additional-cost clause, such as incidental to construction, no payment for this item of work, or cost to be borne by the contractor. These are escape clauses in contract language that attempt to place all of the risk on the contractor. This type of language fools no one and the cost of every item of work will be somewhere in the contractor's proposal. These items of work will be priced and marked up accordingly--the higher the risk, the higher the profit, and thus the higher the cost to the owner. In the end, the owner pays for high-risk projects. Problem areas on jobs should be identified and, if the risk is so high that it will discourage competition of contractors, the owner and engineer should be willing to assume all or part of the risk by eliminating it from the bidding documents and negotiate it with the low bidder after the job is awarded. Reasonable risk sharing should result in lower costs with quality work.

Delays and Changes

Delays in the construction industry can occur at any time throughout the three main phases in the construction process: conception, design, and construction. Satisfaction of federal, state, and local regulations poses numerous and costly delays to owners and engineers. Regulations have increased the front-end costs of a project and the time required between project conception and start of project construction. This section will deal only with delays and changes in scope of work in the construction phase. Table 2 (5) lists contractors' responses to a questionnaire concerning major delay factors that affect their projects. A review of this chart will reveal some items over which the engineer has no control (i.e., weather, labor supply, and subcontractors). Other items, such as design changes, shop drawing and material approval, drawing and specification errors, site access, and utility relocation can be controlled by the engineer. De-

Table 2. Contractor responses to questionnaire based on percentage of replies received.

Delay Factor	Very Important	Important	Minor Importance	No Significance
Weather	59	31	9	2
Labor supply	48	32	16	5
Subcontractors	56	21	15	8
Design changes	36	34	24	5
Shop drawings	23	36	20	20
Foundation conditions	27	30	28	15
Material shortage	23	31	32	14
Manufactured items	19	32	31	18
Sample approvals	17	29	33	21
Jurisdictional disputes	17	27	27	29
Equipment failure	13	19	43	25
Contracts	13	18	30	39
Construction mistakes	10	17	39	33
Inspections	6	17	46	31
Finances	8	12	26	54
Permits	10	9	29	52
Building codes	2	8	27	63

Note: Rows may not total 100 due to rounding.

lays in the field, regardless of their nature, must be eliminated. If there are some delays in order to make use of technological advances, the owner must evaluate and compensate accordingly. The contractor's supervision, field offices, labor, and equipment, which cost thousands of dollars per day, are wasted while a design change is being considered.

The best way to avoid delays and minimize claims is for each actor to know his or her rights and protect them. The engineer should read the contract, plans, and specifications thoroughly and know what is expected before construction begins.

The engineer should conduct a thorough subsurface investigation to document soil conditions expected to be encountered. This should eliminate any delays due to differing site or concealed subsurface conditions. Drawings and specifications should be accurate and pertinent. Site access should be available and major utility relocation scheduled before construction begins. Design should be constructible by using reasonable techniques.

Regardless of the amount of time spent designing and scheduling, job problems and delays will occur. Problems should be identified early. The engineer should have a specific format to handle delays quickly and expeditiously and within a specified time frame so as to minimize the amount of additional cost to the contractor.

CONTRACTOR'S ROLE IN THE TOTAL SYSTEMS APPROACH

Once a low bid is submitted and the project is awarded, a construction team is selected from the available personnel. Our construction team consists of a project manager in the office and general superintendent, superintendent, craft foreman, and clerical staff in the field. This staff may vary depending on the size and complexity of the project.

Drawings and specifications are given to the field personnel so they can familiarize themselves with the project. The estimating team is available to the field personnel for consultation and advice in explaining the estimate, schedule, and tentative techniques to be employed. We will never start a project prematurely because we believe in the adage, "haste makes waste".

After the construction team is familiar with the project, a master schedule is made that incorporates the accountability of the owner, engineer, utilities, and others. This schedule should be as detailed as possible and incorporate every restraint and delay that can be envisioned. Critical path schedules and time grid schedules are used. We prefer the time grid, which uses a bar graph format and shows the interrelationship between various activities. The schedules are updated monthly. From the master schedule, separate schedules are made for the major subcontractors and distributed to them.

During the initial scheduling phase of the project, the project manager tends to the various administrative aspects of the contract, such as execution of contract, bonds, insurance, equal employment opportunity program, quality control program, and purchasing of subcontracts and all necessary materials.

Once construction starts, the management in the field has two basic goals:

1. Get the project completed within the original estimated budget and
2. Get the project completed within the original time frame estimated.

The project manager has these same goals, plus the elimination of delays and prevention of problems before they occur.

Throughout the job, proper and constant communication is vital between the team players. Biweekly meetings were held at the job site among the owner, engineer, contractor, major subcontractors, and utilities. Problems and job progress were discussed and deadlines were established. Everyone was held accountable to the deadlines established. Cameron Construction Company held weekly meetings with field personnel at the end of the day. The participants were the project manager, general superintendent, superintendent, and craft foreman. The following items were discussed at these meetings:

1. Costs,
2. Job progress and use of short-interval schedule (weekly),
3. Problems,
4. Problem-solving techniques (example of wall bulkhead), and
5. Method improvement techniques.

The main purpose of these meetings was to get field personnel involved and accountable. Costs were not hidden and job performance could be readily evaluated. Problems were discussed and analyzed. Our motto is that there is always a better way, a best way that is never truly achieved.

Motivation is maintained through bonus programs and other incentives.

In summary, the total systems approach produces a productive atmosphere for quality construction. The salient points of this approach are as follows:

1. Immediate establishment of professional trust and mutual respect among owner, engineer, and contractor;
2. Team concept--everyone works together toward the same common goal;
3. Profit is not a dirty word;
4. Owner and engineer are willing to share risks;
5. End-result specifications are to establish performance standards to be met;
6. Specifications tell what is required, not how to do it;
7. Quality control is the contractor's responsibility;
8. Qualified inspectors should understand construction; specifications should be used as a guideline, not a bible;
9. Elimination of delays in the field by anticipating them before they occur;

10. Decisions should be readily obtainable--management of owner and engineer should not be multilayered, no procrastination; and

11. Commitment by the utilities to cooperate with contractor.

CONCLUSION

There is no magic formula for success to a construction project. Common sense should govern all decisions. Among the secrets to improved contractual relationships and quality construction are creating a climate of respect and goodwill among the owner, engineer, and contractor; a willingness to adjust specifications to simplify construction while holding fast to end results; a willingness of the owner to assume risk for unforeseen conditions encountered and not let everything fall on the contractor's head.

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Analysis and Application of Correlated Compound Probabilities

RICHARD M. WEED

Many statistical applications require the calculation of compound probabilities and, frequently, the individual probabilities are not independent. The failure to recognize that correlation exists in cases such as these has resulted in numerous errors in the published literature. Although an exact analytical solution is not known, problems of this type can often be handled effectively by calculating lower and upper bounds for the desired compound probabilities. Bounds for both positively and negatively correlated cases are derived and then applied in the analysis of statistical acceptance procedures. The results of several computer simulation tests are presented to demonstrate the validity of the theoretically derived results.

The analysis of a variety of statistical acceptance procedures requires the calculation of compound probabilities. In many cases, the individual probabilities are correlated to some unknown degree, which precludes the direct calculation of the desired compound probability. However, lower and upper bounds for the desired probability can be calculated and, provided these bounds are not too far apart, this furnishes an interval estimate that is sufficiently precise for most practical purposes.

A previous paper (1) developed this approach for the case in which the individual probabilities are positively correlated. This paper repeats the derivation for positively correlated probabilities, develops the derivation for negatively correlated probabilities, applies these results to a simple sequential sampling scheme, and then derives the bounds for the probability of acceptance under a more complex acceptance procedure. This latter application is then checked by computer simulation.

BOUNDS FOR POSITIVELY CORRELATED PROBABILITIES

In accordance with a law of probability that is usually referred to as the general law of multiplication (2), the compound probability for the joint occurrence of event A and event B is given by Equation 1. Under this law, no assumption is made concerning the independence of these events, and they may be either positively or negatively correlated.

$$P(A \cap B) = P(A \mid B) \cdot P(B) = P(B \mid A) \cdot P(A) \quad (1)$$

When events A and B are correlated to some unknown degree, the values of $P(A|B)$ and $P(B|A)$ are not known and, consequently, $P(A \cap B)$ cannot be evaluated directly. However, when two events are positively correlated, the occurrence of one increases the likelihood of the occurrence of the other. This can be expressed in equation form as

$$P(A \mid B) \geq P(A) \quad (2)$$

which, when substituted into Equation 1, yields

$$P(A \cap B) \geq P(A) \cdot P(B) \quad (3)$$

as the lower bound for $P(A \cap B)$.

To obtain the upper bound, remember that any probability value is less than or equal to unity. Therefore, since $P(A|B)$ and $P(B|A)$ in Equation 1 both must be less than or equal to one,

$$P(A \cap B) \leq P(A) \quad (4)$$

$$P(A \cap B) \leq P(B) \quad (5)$$

and, from this,

$$P(A \cap B) \leq \mathrm{Min}[P(A), P(B)] \quad (6)$$

is derived as the upper bound.