A Case Study in Army Combat Modelling

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ABSTRACT

This paper demonstrates an approach to army combat modelling using system dynamics. A model is presented of an enemy ground advance which is used to analyse how various adaptive strategies by the attacker and defender during the advance can lead to different outcomes when the combatants meet. Particular attention is paid to the development of performance measures and to the interpretation of results in terms of the underlying feedback structure of the model.

INTRODUCTION

During the last two years, a series of investigatons have been carried out within the University of Bradford Management centre into the use of system dynamics as a modelling methodology for army defence analysis. The objectives of the work have been to examine and demonstrate the use of the approach for creating insights into situations involving complex operational interactions between personnel and equipment. The purpose of this paper is to communicate one particular model developed during this programme of work which captures the basic philosophy of the approach as well as clearly demonstrating the type of insight which can be achieved. This is referred to as the armoured advance model.

THE ARMOURED ADVANCE MODEL

Most traditional modelling of ground conflict has centred on assessing the actual outcome resulting from the face to face confrontation of two combatants. Such low aggregation, high resolution modelling is not considered here. Instead emphasis is placed upon assessing the use of indirect strategies aimed at avoiding situations occurring where face to face confrontation will lead to a defeat. That is, in the defenders terms, the aim is to design indirect strategies which will result in reducing those characteristics of the attacker (such as speed and force size) to an acceptable level on arrival at the attackrs position. Conversely, in the attackers terms the aim is to design strategies which will result in preserving such characteristics. This approach is in line with a growing trend in defence analysis towards the modelling of command, control, communication and intelligence interactions (Huber, R.K. 1985), rather than detailed combat.

The objective of the amoured advance model was therefore to investigate the merits of alternative defensive (blue) strategies for slowing down the advance of an attacking force (red), under a number of adaptive strategies by the latter concerning the timing of it's formation changes. General defence thinking on this issue suggests that basically red's alternatives are to change to more widely dispersed formations early in the advance, in order to reduce their vunerability, or to maintain a dense formation for as long as possible, since a higher speed is attainable.

This is a diffuse, ambiguous and subjective question, in that vunerability and dispersion are concepts which are difficult to define and quantify. It is also complicated by containing both spacial and time dimensions.

A system dynamics model was developed using a stepwise approach to conceptualisation (Wolstenholme and Coyle 1983) and this resulted in a sizeable quantitative model. Figure 1 shows a reasonably detailed qualitative diagram of this model which was used to communicate the relationship between the model and reality. The actual movement of red's advance can be traced by the variables across the top of the diagram. Units for the advance are assembled in a pre-defined area and advance takes place firstly, in a dense 'battalion' formation, secondly in a slower but more dispersed 'company column' formation and finally in a very slow, very dispersed 'platoon column' formation. The key strategy variables for red in this chain are the rates of deployment between formations, which are considered to take place at a fixed distance (preplanned response) or a variable distance (adaptive response).

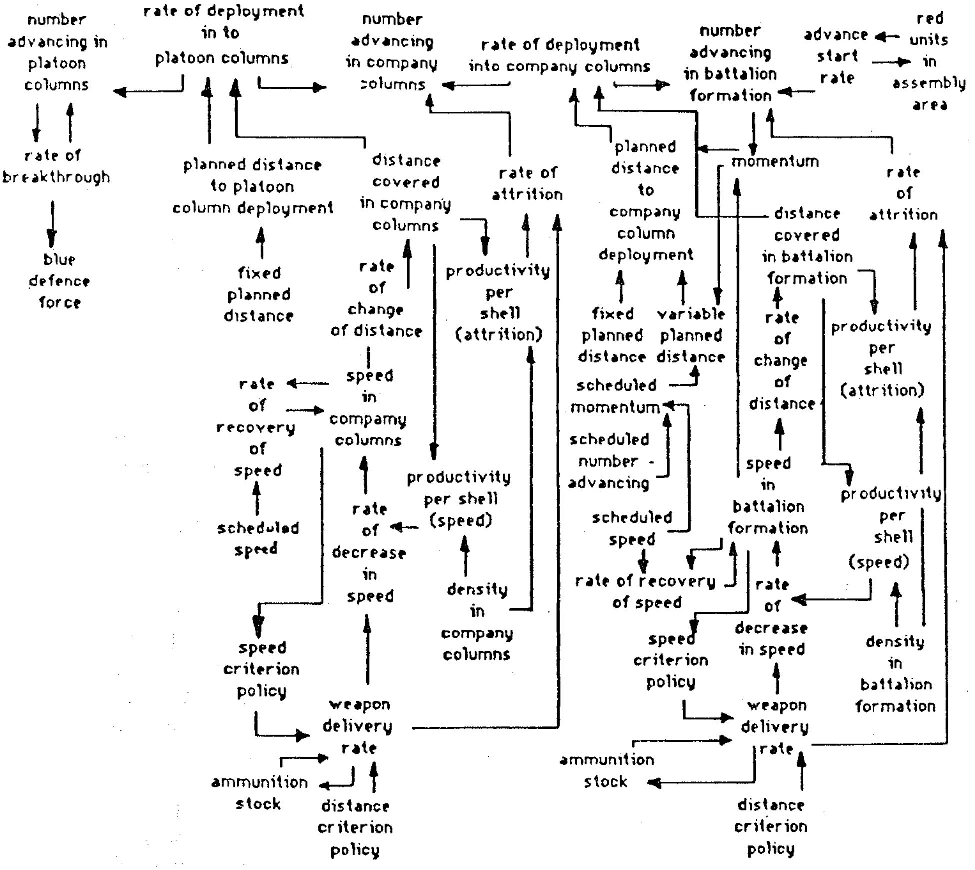

FIG.1. INFLUENCE DIAGRAM OF THE ARMOURED ADVANCED MODEL

The variable distance strategy represents an attempt by red to delay formation change to take advantage of the higher scheduled speed associated with the denser formations and a number of secondary strategies for red exist by which to determine the variable distance. These could be to base the decision on say speed or momentum (speed * number advancing), with the formation change point being delayed more and more as these variables fall behind schedule as a result of blue fire. Momentum is an often used concept in military analysis but is not often used as a quanitative measure as here. The key strategic variable from blue's point of view is of course the effectiveness of it's fire delivery, in terms of both red speed reduction and red attrition. It will be seen that the effectiveness of fire is defined in Figure 1 in terms of both speed reduction and attrition and that it is itself made to be a function of the rate of weapon delivery and the productivity per delivery. Productivity of fire is an interesting concept which is analogous to managerial labour productivity. This productivity is obviously a function of the distance over which fire takes place (accuracy) and the density of the target, which is in turn a function of the type of formation assumed by red. There are various strategies available to blue for the delivery of fire. Three possibilities for this might be to base fire on red distance or speed (shown in Figure 1) or red momentum. It is assumed in Figure 1 that red can recover speed where blue firing ceases.

The lower part of the diagram in Figure 1, which displays variables relating to blue fire delivery, speed and distance, are replicated for the battalion and company column situations and various links between the two are omitted for clarity. The most important of these are, perhaps, the constraints associated with the red decision to change between formations. In the case of red using distance as a formation change decision variable, it was assumed that there would be no point in red holding on to a battalion formation beyond the point at which it's speed in this formation fell below that achievable in company columns. The same argument applied under a formation change decision based on momentum, when the momentum in battalion formation fell below that achievable in company columns.

The above description is an overview outline of the model structure and major strategy options which the model is capable of addressing. Some examples of results from the model are contained in Tables 1 and 2. Here, a matrix output of results for each red/blue strategy combination is shown. The performance measures used were the time to company column deployment, the total time for red to reach blue, the size of the red force

BLUE STRATEGY	RED STRATEGY							
	Company Column Deployment at a Fixed Distance				Company Column Deployment at a Variable Distance			
	Time to company column deployment (hours)	Time for red to reach blue (hours)	Size of red force on arrival at blue position (units)	Momentum (Units) / (hours)	Time to company column deployment (hours)	Time for red to reach blue (hours)	Size of red force on arrival at blue position (units)	Momentum (Units) / (hours)
Fire delivered on a distance criterion	4.44	10.25	1598.50	155.37	4.75	9.25	1592.30	172.78
Fire delivered on a speed criterion	5.88	13.19	1295.00	98.17	7.62	10.56	1098.00	103.99
Fire delivered on a momentum criterion	6.75	14.38	1219.00	84.80	9.06	10.81	1000.00	92.51

TABLE 1 Example of model results for the case of light fire delivery by blue

BLUE STRATEGY	RED STRATEGY							
	Company Column Deployment at a Fixed Distance				Company Column Deployment at a Variable Distance			
	Time to company column deployment (hours)	Time for red to reach blue (hours)	Size of red force on arrival at blue position (units)	Momentum (Units)/(hours)	Time to company column deployment (hours)	Time for red to reach blue (hours)	Size of red force on arrival at blue position (units)	Momentum (Units)/(hours)
Fire delivered on a distance criterion	4.38	10.25	1526.30	148.90	4.813	9.13	1517.20	168.46
Fire delivered on a speed criterion	6.32	14.63	726.00	49.70	4.87	16.38	864.00	52.00
Fire delivered on a momentum criterion	6.56	13.50	787.00	58.34	8.25	9.56	707.00	73.97

TABLE 2 Example of model results for the case of heavy fire delivery by blue

on arrival and the momentum of the red force on arrival (arrival size/arrival time). In each table two red strategies are defined for company column deployment and three blue strategies are defined for fire delivery. Table 1 is for a low rate of fire delivery and Table 2 for a high rate of fire delivery. Some overall conclusions can be drawn for this set of results. First from red's point of view. When faced with a low rate of blue fire delivery and if the major objective is to advance in the minimum time, it would appear best for red to delay formation change for as long as possible. However, to maximise the numbers arriving then red should change formation as early as possible. In order to maximise the momentum of arrival then again red should defer formation change for as long as possible. When faced with a higher rate of fire similar conclusions follow except when the previously defined constraints come into play. In particular the effect of the constraints can be seen in the second row of results in Table 2, when fire is delivered on a speed criterion. Here, a very early change of formation takes place by red on the variable distance strategy, the total time of red to advance is increased but more units arrive; again giving a better arrival momentum.

From blue's point of view the results indicated that it was always preferable to deliver fire on a red speed, rather than red distance, criterion under any of the performance measures. It would appear that it was better still, for blue to deliver fire on a criterion of red momentum. However, this strategy did not ultimately generate as low a final level of red momentum as that achieved when fire was delivered on a speed criterion. This latter result, which is depicted in Table 2, is again apparently associated with the activation of the speed constraint.

The above preferences in blue fire delivery criteria would appear to be confirmed in terms of the efficiency of ammunition useage as shown in Table 3. Table 3 also suggests that light fire is more economical than heavy fire in reducing red's momentum.

THE UNDERLYING FEEDBACK MODEL

Whilst the foregoing model and results presentation is perhaps adequate and may answer some specific questions, it is possible to generate more general insight and understanding by developing a simplified but very explicit qualitative model of the feedback processes at work. Such a model will now be developed and used to explain the previous results. However, a certain amount of abstraction is involved in the creation of such a diagram in this case, and the resultant model will be seen to lose it's one to one correspondence with the physical reality modelled which existed in Figure 1.

BLUE STRATEGY		RED STRATEGY					
		Company Column Deployment at a Fixed Distance			Company Column Deployment at a Variable Distance		
		Red Momentum on arrival at Blue Position	Shells Delivered	Average Reduction in momentum per 1000 shells	Red Momentum on arrival at Blue Position	Shells Delivered	Average Reduction in momentum per 1000 shells
Fire Delivered on Distance Criterion	light	155.37	4418	7.71	172.78	3306	4.39
	heavy	148.90	6656	6.10	168.46	5437	3.86
Fire Delivered on Speed Criterion	light	98.17	8837	10.33	103.99	6956	12.20
	heavy	49.70	19406	7.20	52.10	22500	6.10
Fire Delivered on Momentum Criterion	light	84.80	9668	10.80	92.51	6912	14.00
	heavy	58.34	16688	7.86	73.98	9281	12.44

TABLE 3 Comparison of the average reduction in red momentum achieved per 1000 shells fired, for each combination of red/blue strategy.

Figure 2 shows an influence diagram of the basic model feedback structure focusing on the effectiveness of blue fire in reducing the speed of the red advance, when the planned distance to each formation change is based on a comparison of the actual to scheduled distance-achieved. It will be seen from Figure 2 that four major feedback loops exist. The one around the left hand side of the diagram (loop A) is a negative loop by which red attempts to control (maintain) it's speed. As actual speed declines (as a result of blue fire) and the achieved distance (relative to the scheduled distance) falls, the planned distance to formation change is put back; resulting in a later formation change, higher density of formation and higher scheduled speed. Speed erosion within a formation will, however, take place because as long as a high density formation is maintained the productivity of blue fire and hence it's effectiveness, remains high. This effect can be traced at around the positive feedback loop on the right hand side of the diagram (loop B). Ultimately speed erosion will short circuit both of these loops via the dotted constraint link, which will momentarily reverse the polarity of both loops.

The other two feedback loops in Figure 2 relate to the effect of red's distance of advance on the productivity of blue fire (loop C; a negative loop) and the 'rate of recovery of speed' loop (loop D) by which red's speed rises, whenever blue fire ceases.

It is important to note here that red size as clearly indicated in Figure 2 does not play a role in determining red strategy, but it is purely an output variable.

Figure 2 provides a clear explanation of the previously presented results and conclusions for red strategy, which centres on the effect of the important but rather inconspicuous loop, in Figure 2, associated with speed recovery (loop D), and the way in which this relates to the strategy of the combatants. The basic insight generated here is that speed and size as system variables have very different characteristics. The most important of these differences is that the former is recoverable by red if blue firing stops, but that the latter is not. Consequently, momentum as a system variable has a recoverable and a non-recoverable component. As a result, when momentum is used as a system performance measure, there is an underlying downward trend in performance as blue fire takes place. This is recoverable, but then only in part, when firing stops. This explains why light (or more accurately, spasmodic) fire by blue is the least effective strategy for blue and will result in high momentum being achieved by red and a preferred tendency by red to maintain a dense, higher

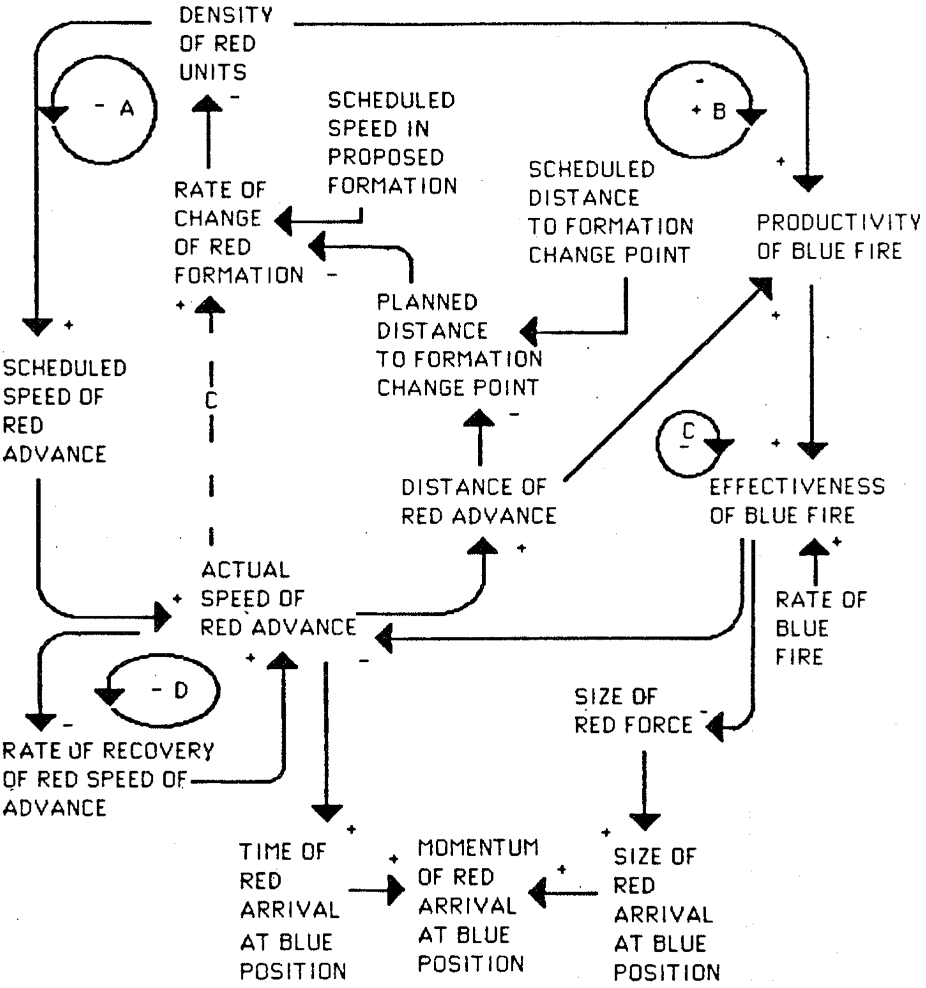

FIG. 2. UNDERLYING FEEDBACK STRUCTURE OF THE MODEL

(WITH RED FORMATION CHANGE DECISION BASED ON THE DISTANCE OF THE RED ADVANCE.

speed formation. Conversely, heavy (or more accurately, continuous) fire is the most effective strategy for blue and, if maintained, will result in complete destruction of red unless the latter operates a constraint for aborting from the denser formation, when an intolerable situation occurs. Even when this results in an early formation change, however, it would appear that red's arrival momentum can still be higher under a variable-distance, formation change strategy, than under a fixed distance strategy. However, not significantly so since, as indicated in Figure 2, it must always be detrimental to red to eliminate it's opportunity to recover speed.

Figure 3 shows a revised influence diagram which captures the effect of red basing it's planned distance to formation change on the product of the red size and speed (momentum). This figure incorporates a momentum constraint based on a scheduled momentum for the next formation, which is a product of the scheduled speed and scheduled (minimum) size of force tolerable for entry to the next formation. The purpose in showing this figure is to emphasise the fact that the use of red size, as a product of speed to create a momentum decision variable to determine the planned distance is formation change, does in no way change the polarity of the loops described in Figure 2. Figure 3 is therefore identical in feedback terms to Figure 2.

Figure 3 also includes the feedback loops associated with blue's strategies for fire delivery. That is, based on red's achieved distance, speed or momentum. These are all negative feedback loops which attempt to control red's speed and size. This presentation focuses attention on the different degrees of directness of these strategies and implies, as born out by the quantitative results, that the most effective strategies will be the most direct ones (speed or momentum based). However, once again, an important consideration is the consistency of fire delivery. It is important to note here that it is often the case that firing is deliberately switched on and off as a result of the definition of the fire delivery strategy itself; for example where firing is switched off when momentum or speed are reduced to pre-set lower limites and switched on again when these variables reach pre-set upper limits. An intermittent blue fire strategy constructed in such a seemingly logical way will, in fact, be self defeating as it facilitates recovery of speed and momentum by red. A further factor brought to the fore here is that of the compatibility between the criterion for fire delivery and the performance measure used. For example, if fire delivery is based on maintaining momentum at a given target level and performance is measured in terms of momentum, then the performance will be determined by the target set by the strategy which may not be, ultimately, as low as intended.

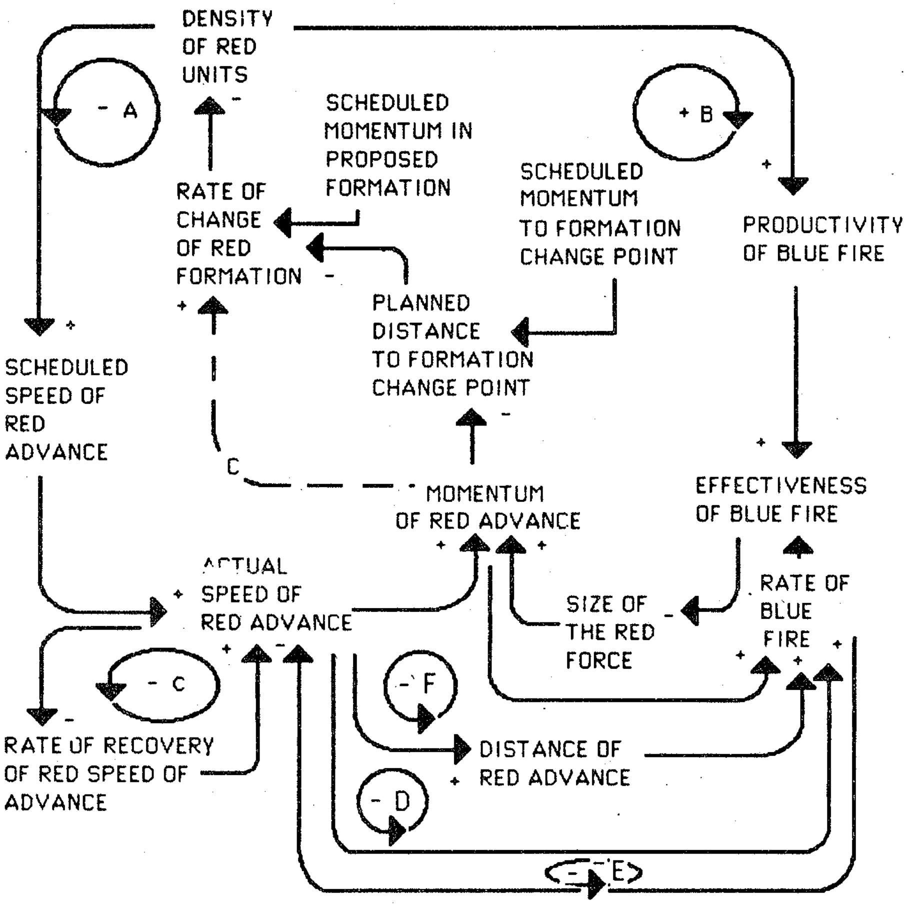

FIG. 3 UNDERLYING FEEDBACK STRUCTURE OF THE MODEL

(WITH RED FORMATION CHANGE DECISION BASED ON THE MOMENTUM OF THE RED ADVANCE AND SHOWING THE BLUE FIRE DELIVERY STRATEGIES.

FACILITATING MODEL DEVELOPMENT AND FURTHER INSIGHT

The parallel development of quantitative and qualitative models as used here to aid and extend problem analysis is formally and generally shown in Figure 4. This figure also suggests that the insights gained can lead to further model development.

An example of the use of this procedure in the current defence model centres on the possibility of changing the assumption in the model concerning the fact that a change of formation would only take place beyond a fixed distance. An alternative approach would be to allow formation change earlier, if say, cumulative losses became intolerable. This effect could be superimposed in parallel with allowing the existing deferral of formation change due to excessive speed loss. Such a possibility is suggested directly as a result of spotting the lack of a direct feedback link in the current model between red size of advance and the rate of formation change in Figures 2 and 3. The inclusion of such a negative link would create a more direct trade-off in the model between the speed and attrition effects of blue fire on the rate of red formation change. A second example suggested by the existing qualtiative model is the possibility of introducing other alternative strategies by which red could counter the effects of blue fire. One of these would be to introduce a recoverable element to the size of the red force, say by reinforcement. This would mean the advance of a second wave and have consequences for the speed of advance of the first wave, which could be traced out using the model. A third example might be to use the size of the red force as a direct determinant of blue fire via a formal surveillance sector of the model.

CONCLUSIONS

This paper has presented a case study in the application of system dynamics to the analysis of ground defence problems. It demonstrates how low resolution, high aggregation models can be used effectively to analyse the build up to situations of direct confrontation in terms of the indirect and adaptive strategies of combatants. Further, that the results from such a model can provide a quantitative assessment of the outcome from selected strategy combinations. In addition to quantifying the effects of specific strategies, however, it is also demonstrated that insight can be gained from wuch a model into a much more general and wider portfolio of strategies available to both sides, by use of qualitative feedback analyers.

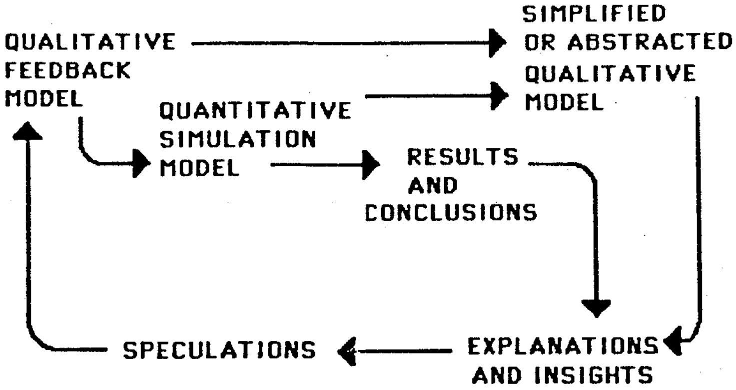

FIG.4. THE PROCESS OF PARALLEL DEVELOPMENT OF QUALITATIVE AND QUANTITATIVE MODELS IN SYSTEM DYNAMICS STUDIES

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