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USE OF CLIMATOLOGICAL DATA IN BUILDING DESIGN WITH RESPECT TO ECONOMY

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Summary

The building sphere with its various planning and operational processes has to be considered a weather sensitive economic system. The impact of weather and climate effects the economic output of building enterprises. By using suitable design weather information in decision making, economic gain may be expected. Published benefit figures are of the order of 0.5 per cent of the total production of the construction industry, while for heating and air-conditioning several times higher relative benefits may be expected.

Zusammenfassung

Das Bauwesen mit seinen verschiedenen Planungsaufgaben und Arbeitsvorgängen ist als wetterempfindliches Wirtschaftssystem zu betrachten. Wetter und Klima beeinflussen den wirtschaftlichen Nutzen von Bauunternehmungen. Werden im Entscheidungsprozess geeignete meteorologische Planungsunterlagen berücksichtigt, lässt sich ein wirtschaftlicher Nutzen erzielen. Für die Bauindustrie wird dieser Nutzen auf etwa 0,5 Prozent des Bruttoprodukts geschätzt; der entsprechende Nutzen für die Heizungs- und Lüftungsindustrie liegt bedeutend höher.

Résumé

On considère la construction - étude et réalisation - comme un système économique sensible au temps. Le temps et le climat ont une influence sur le profit des entreprises de construction. Un profit peut être obtenu en tenant compte, dans le processus de décision, des données météorologiques. Pour l'industrie de la construction, on estime le gain à 0,5 % du produit brut; le gain correspondant est considérablement plus élevé pour l'industrie du chauffage et de la ventilation.

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1. Weather sensitive economic systems

Both economy and the atmosphere are structures of high complexity. It is difficult therefore to follow the effect of a weather event through a weather sensitive economic system, or to estimate the value of information about a weather event in such a system. The basic problem of management is to identify the impact of the weather on the system, respectively on the various activities and processes related with it. The manager is aware that the final product of his enterprise is an economic outcome and has to judge the impacts of the atmospheric environment as potential gains due to favourable conditions, or losses due to adverse conditions (an extended monography on the "value" of the weather is given by Maunder [1]). By considering weather information in his decisions, he intends to follow a strategy for optimizing the economic gain of the enterprise.

Fig. 1, taken from the basic paper of McQuigg and Thompson [2] gives a good overlook of this procedure. The weather sensitive process under management is effected by some actual weather events W and other factors 0 not depending on the weather. In fact, the process depends on a great number of factors besides weather effects.

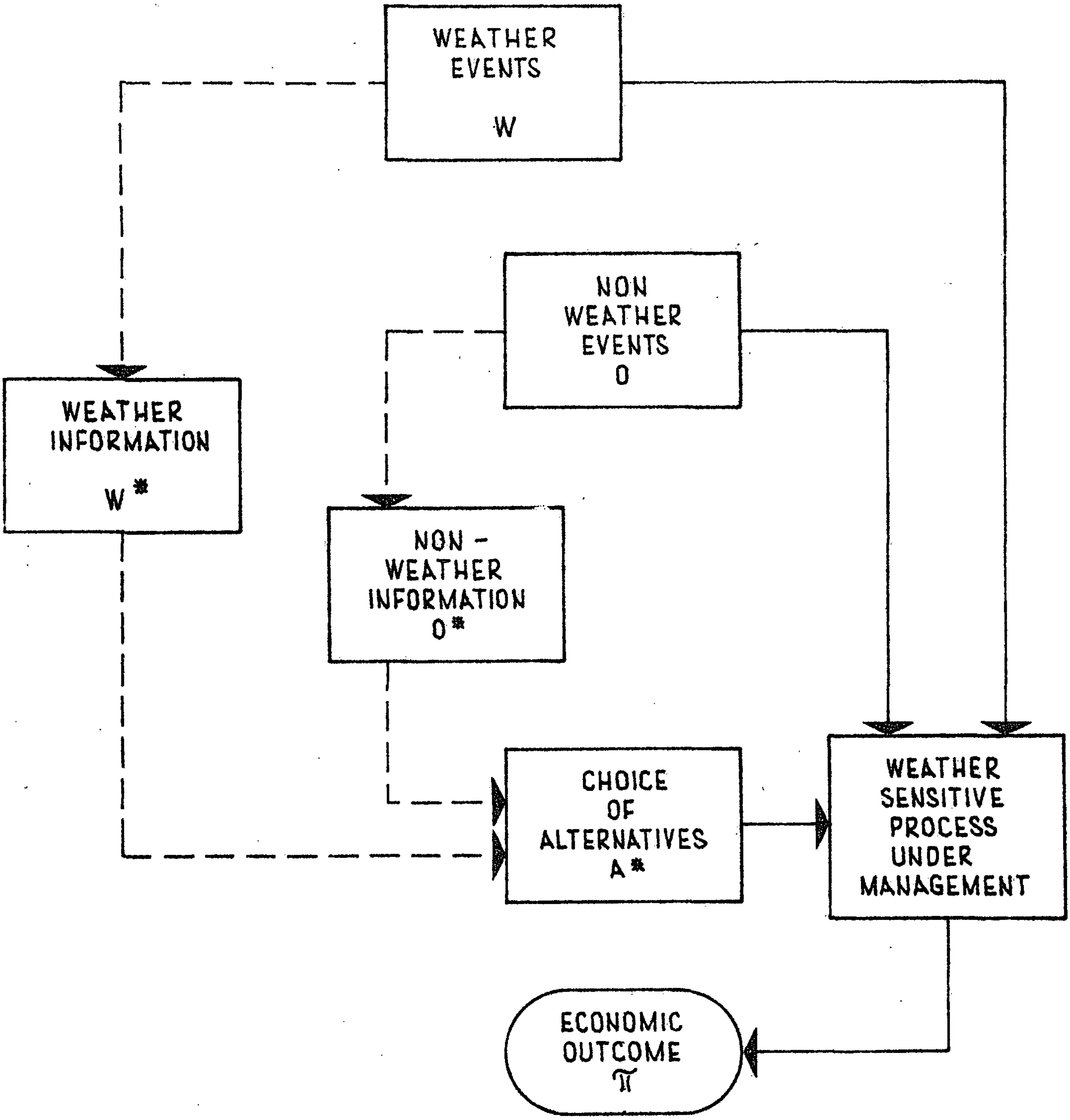


Fig. 1 Schematic outline of relations between weather events, non-weather events, the choice of alternatives by management, and the economic outcome of an enterprise (from McQuigg and Thompson [2]).

Through his decisions the manager can influence the process and by this means influence the economic outcome. At the time, however, when the manager has to decide, only the information W* and O* are available, these being only approximations of the actual values of the impacts W and O, which are not known at the time of the decision making. Since also the relationship between the economic outcome on the one hand and inputs and information on the other, is almost never known exactly, the process underlies further uncertainties of a random nature.

The manager will pose the questions:

- What are the costs of possible actions for accomodating to weather if one wants to
  a) make use of a weather supply (e.g. sunshine in winter) ?
  b) take protection against bad weather ?

In both cases he has to measure the costs of actions against the possible weather gains or losses. He has to be aware that he has to make decisions on the probability of an event happening, and hence he has to count with economic risk; eigher he takes an action of weather accomodation or he doesn't. Hence he will further ask:

- What is the probability, that certain conditions will occur ?

According to <u>Thompson and Brier</u> [3] , to follow the optimum strategy in the long run, the manager should take action if $P > \frac{C}{L}$ and consequently he should not if $P < \frac{C}{L}$; P denoting here the probability of a weather event, C the cost of action and L the losses if no action was taken and the event occurs. With respect to the building industry, these risks are relevant when considering both day-to-day operational decisions and long-range planning. Long-range planning basing on climatological probabilities is much less exposed to unexpected atmospheric impact than the former, however, it generally has decisive economic consequencies.

Summarising, the building manager needs to be informed about the atmosphere, he needs to be informed at the right time and in a suitable way. Besides of that, he of course should know how to use the information. Since he has to make decisions of economic consequence, he must also know the cost of such information and, though this may be small against the total cost of weather sensitive processes, experience shows that this question may yield problems.

2. The metereological subsystem

Let's therefore have a schematic survey on the production of weather information and on its economic aspects (fig. 2). Society wants to be informed on weather and climate and supports therefore a meteorological service; on the other hand, he needs of course industrial products. All decisions of industry are economically orientated, and this fact characterises fundamentally the nature of applied meteorological information. Meteorological service products have to be transformed to information suitable for the requirements of the consumer. These are some kind of forecasts or climatological statistics; generally frequency distributions of different parameters like temperature, wind, sunshine, or also combined distributions of two or more parameters. Several papers submitted to this colloquium show information of this kind. These design data are available for the manager to make decisions. In most cases, he needs them for the day-to-day operational work, and less on the level of planning and least on the highest planning level for developing technical norms and standards.

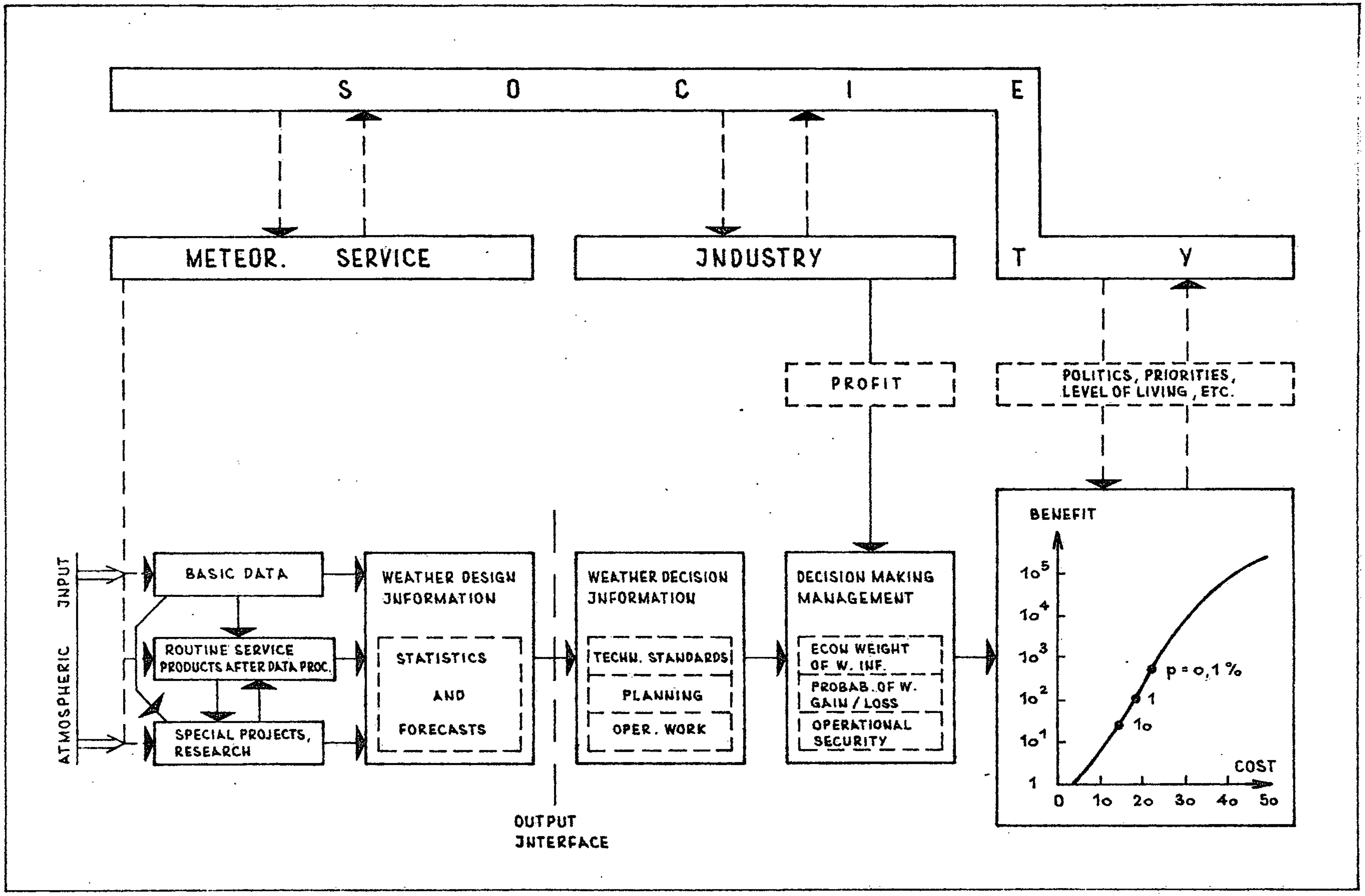


Fig. 2 Model survey on the production of weather design information and on its economic aspects.

The higher the level at which the information is used, naturally the greater its economic effect. Depending on the economic significance of the information, the manager can decide how much money to invest when accomodating to weather. According to the type and purpose of the building, or by similar reasons, he also has to decide on the operational security requirements. The probability p indicate the cases of 100 when system performance is insufficient.

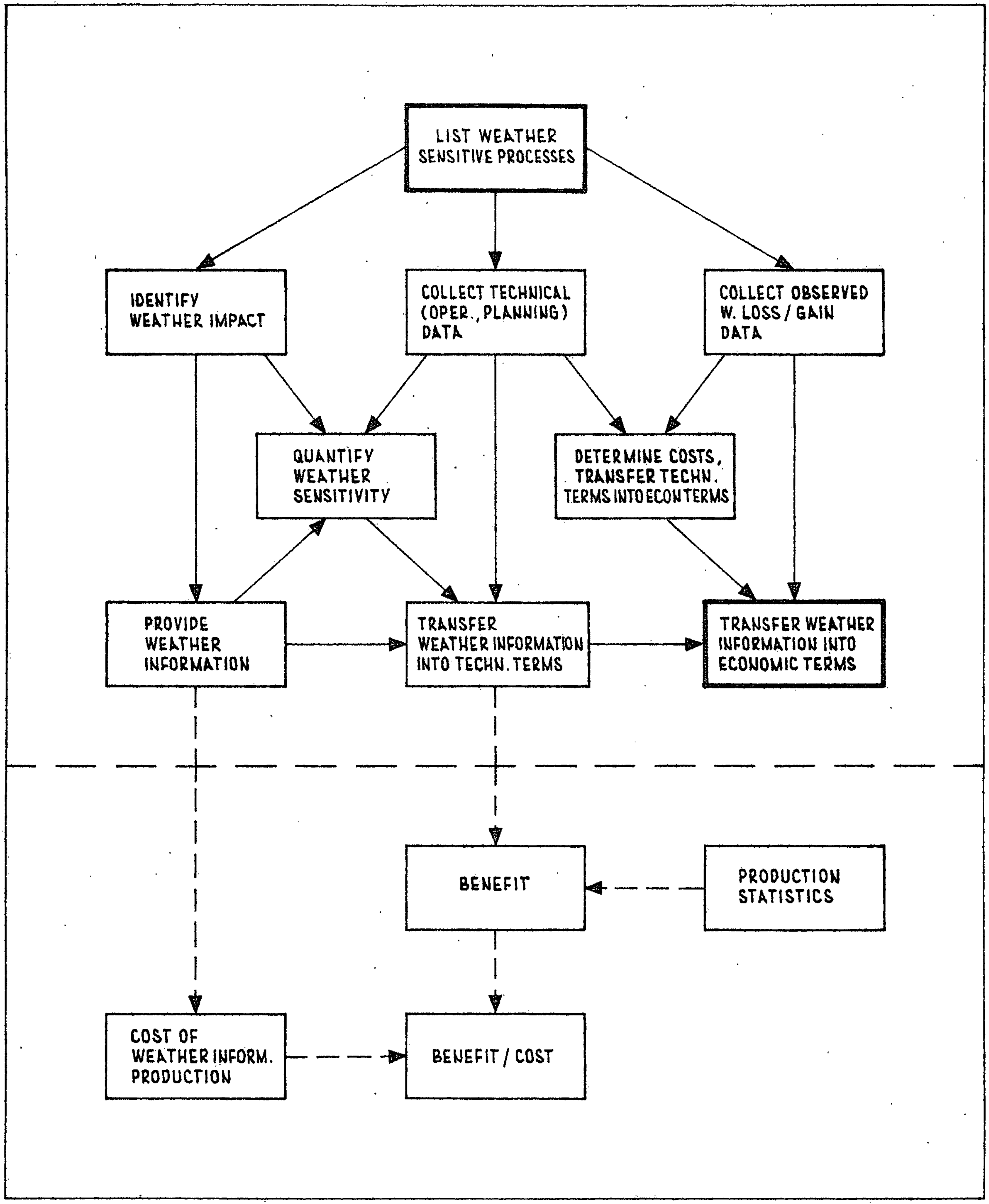
The scheme indicates that the final product of a meteorological service yields benefit only, if used for some decisions. Considering benefits, the essential question is: benefits for whom ? For the direct user, in our case for the building industry ? Yes, obviously, that is hoped to be the case. But the same information usually gives other advantages and benefits too, both in the public and the private sector. It can also be said that better building as such is as much a government affair as the building industry's. The competition for government funds is strong and although the benefit/cost ratios of weather information might be most attractive, the politician has to consider other aspects too and will set priorities. The concept of design weather information is relatively new and is not considered everywhere as belonging to the conventional tasks of a meteorological service. This point has to be mentioned, because the production of this information should happen on a broad scale under rational conditions, so that optimum economic efficiency can evolve.

3. Benefit estimations of design weather information

3.1. Estimation procedure

Let's now have a synopsis on actual available benefit estimations. It has of course to be said beforehand, that efforts to estimate benefit values are relatively new and hence, not much material is at disposal. Also, considering the complexity of the problem, only more or less rough estimates can be expected. Considering furthermore that published benefit values or data usable in estimations, are spread in the literature over several disciplines (economics, engineering, meteorology and other,(see McQuigg[4]), the material is heterogenous and the methods applied are different.

Fig. 3 tries to illustrate common features of the different efforts. The starting point is to separate the weather sensitive processes and activities of the whole enterprise and prepare a list. - As further step, it is necessary to determine the meteorological, technical and economic characteristics of these processes and activities. Identifying weather impact, means generally defining some critical values of temperature, wind, rain etc. or of combined quantities. - The collection of technical data both concerning operation and planning may contain construction log entries, data on insulation, data on consumed heat, or also the connexion between these two, data on material impairments, time requirements of certain operations etc. - It is necessary furthermore to assess costs, to find the monetary equivalent associated with all these technical terms (examples of useful compilations on various cost-components are given by Milbank et al.[5], Hardy and Mitchell[6], Rowe[7], Glas and Höglund[8], Robertson[9] and Spencer[10]). - Information about weather impact means the design weather information



<u>Fig. 3</u> Scheme showing courses of step-by-step procedure to find the economic value of weather decision information.

(forecasts, probabilities, or combined probabilities) mentioned earlier. Through the comparision of weather impact data or weather information with operational and planning data it is in some cases possible to express weather sensitivity in quantitative terms, e.g. percent of total construction volume or percent of operation time, etc. - Combining these values or direct technical data with weather information, the following step is the transfer of weather information into technical terms. - The last task is to transfer weather information into economic terms. In this procedure, of course, direct observations, if available, on losses due to weather demage (or also gains, as for instance reduction of heating costs by solar energy gains) might be useful too.

Additionally to these solution procedures, in some cases, acceptable results may be produced by using data on weather sensitivity or other technical and also economic information, stemming from other firms or other countries. These may then be transformed to "home" conditions, provided, that meteorological and other reasoning permits this transfer. By comparing these data with production figures, e.g. with data on gross national production, further benefit values may be estimated (lower part of fig. 3). By checking the credibility of these "pseudo" estimates, benefit/cost ratios allied to different results, might then be computed and compared with each other. The cost of weather information might be find out by regarding the internal structure of a meteorological service (sophisticated techniques were developed by Czelnai, Dési and Szepesi [11] and Czelnai [12].

3.2. Benefits for the construction industry

A survey on different sectors of the building sphere, where economic benefits from using climatological services may be expected, is given by Clements[13]. Considering figures, tab. 1 presents a compilation of available benefit estimations. The table shows that estimated potential benefits by using weather information amount to some 0.3 - 1.0 per cent of the gross national production of the construction industry.

Russo and collaborators[14, 15] have prepared a list of 43 construction operations which are, to some extent, influenced by weather and spread through almost the entire spectrum of construction activities. By collecting a large amount of data and documents on the meteorological, technical and economic aspects of these operations throughout the U.S.A. and analyzing relationships between these data, as outlined by the diagram (fig. 3), it was found that 45 per cent of the total construction volume of the U.S.A. was potentially weather sensitive, which gives about 40 billion $ for 1964. Considering the present accuracy of weather information and supposing that it is appropriately used by the industry, the potential annual saving would amount to 0.5 - 1.0 billion $, this being of the order of 1 - 2.5 per cent of the weather sensitive volume, or about 0.6 - 1.2 per cent of the gross national production (of the construction industry).

Estimations for the U.S., the U.K. (Mason[16] and for the German Federal Republic (Süssenberger[17]) are based on the present accuracy of weather information. On the

Table 1 Compilation of published benefit estimations available for the construction industry.

Author	Year of reference	Land	Weather Sensitive Portion (WSP) of total construction volume		Potential Benefit Using Weather Information			% of Losses/ Year	Benefit/ Cost
			10^6 $ / Year	% of GNP	10^6 $ / Year	% of GNP	% of WSP		
Russo	1964	U.S.A.	40,000	45	500-1,000	0.6-1.2	1.25-2.5	10-17	
Mason	1966	U.K.			25 (10 mio £)	0.35		10	40
Süssenberger	1965	G.F.R.			60	0.5			
Thompson	next years	World Total			3,000				> 50
EMCC Study Group	1980	Europe (17 Countries)		>40	97-130 (194-260)	0.45 (0.9)			> 100

other hand, expected benefits by the World Weather Watch (WWW) - Project (Thompson [18]) are related to an expansion of the network of metereological observing stations, including the use of weather satellite observations.

The study group pf the project of the European Meteorological Computing Centre (EMCC) [19] estimates future expected benefits due to improved medium-range (4 - 10 days) forecasts. The justification of possible realizing the EMMC-plan was judged by estimating prospective benefits for the year 1980 for 17 European countries. Expected total benefits were gained in a five step-procedure:

- estimation of output in 1980
- calculation of present value at two alternative discount rates (5 and 8 % / year)
- derivation of the proportion of weather-sensitivity in certain cases
- application of average benefit percentage obtained by interviews (= possible benefits)
- reduction of the result to a lower figure (= expected benefits) by considering that most probably only partial use of forecasts will be made.

This study was mainly based on the results of a questionnaire action taken in various countries and extended over several sectors of the economy. Considering the construction industry, all together 55 questionnaires, containing quantitive benefit estimates of different firms, could be evaluated. 33 of these 55 estimates were spread over the wide range of 0.1 to 5 percent, 16 interviews resulted in the figure ≥0, without further specification and 6 entrepreneurs were of the opinion that no benefit at all may be expected by using medium range forecasts. The result of these estimates gave 0.9 % potential benefits and 0.5 % expected benefits, as mean values. These figures were considered as valid for the total construction production of all 17 countries. With respect to the expected annual costs of the EMCC-project and assuming, only half of the total costs generates the expected 100 - 130 million $ benefit for the construction industry, a benefit/cost - ratio of >100 may be estimated.

Further instructive results of econoclimatic estimations may be attained by developing and applying simulation models, as was particularly shown by <u>McQuigg</u> [20] and others (<u>Maunder, Johnson</u> and <u>McQuigg</u> [21, 22] , <u>Johnson and McQuigg</u> [23] , <u>Johnson et.al.</u> [24] , being recent examples in the construction field).

The impressive conclusion of a most recent study of <u>Buchert, McQuigg and others</u> [25] is, that variations on costs induced by weather are about the same magnitude as twice the profit margin on many large construction projects. Let's summarize the procedure in brief:

- The building process of an auditorium roof, once using concrete and once using steel, was simulated under varying weather conditions. All technical characteristics, e.g. dimensions, form, quantity and specifications of building material, etc. were defined.

- Quantitative expressions, relating weather events and construction data, taken from daily log entries of a large building project in Kansas City, Missouri, were developed. A four-year sample of actual data was included in this processing.
- The model was then applied to a 19 years period of hourly weather data, both for Columbia, Missouri and for Buffalo, New York, to produce daily probability values for different construction activities for different climatic conditions. Work - no work decisions were made depending on these probabilities, and expected costs were computed for each activity. Collecting actual weather data, the consequencies of the decisions were then determined both on the $ costs and on the duration of the project.
- 218 runs of this simulation model were made to test the effects of changing the starting date of the process and to test the effects of regional variations of weather conditions on the cost and project duration for each type of shell.

Table 2 shows that due to weather effects, process duration of the concrete shell vary between 192 and 315 days, associated with a cost interval of $ 260,000 to $ 329,000, while the corresponding values in case of the steel shell are 66 and 147 days, as well as $ 70,000 and $ 123,000, respectively.

Table 2 Experimental results of the simulation model by Buchert, Mc Quigg et al.

(a) Concrete Shell - Raw Cost[1] = $241,261.25 Raw Duration[1] = 151

	1 March		1 April		1 May	
Location	Cost	Dur.	Cost	Dur.	Cost	Dur.
Columbia						
Mean	259,855	192.2	276,371	213.7	271,697	203.3
S.D.	7,906	14.3	8,273	15.4	6,167	11.5
Buffalo						
Mean	295,316	273.8	329,116	314.7	321,962	304.2
S.D.	20,040	40.2	36,826	48.2	28,046	38.8

(b) Steel Shell - Raw Cost[1] = $51,946.37 Raw Duration[1] = 37

	1 January		1 March		1 September	
Location	Cost	Dur.	Cost	Dur.	Cost	Dur.
Columbia						
Mean	69,546	66.2	85,536	84.9	71,276	68.3
S.D.	9,003	18.6	8,147	23.8	3,025	5.2
Buffalo						
Mean	122,132	147.5	122,941	143.6	92,471	106.5
S.D.	19,912	26.0	21,897	31.0	14,620	19.6

[1] Costs are in dollars, while durations are in days.

3.3. Benefits for the heating - air-conditioning industry

It seems to be evident, that heating and air-conditioning are influenced by weather and climate to a higher degree than construction, as a whole. Hence, by using suitable climatic information in heating and air-conditioning design, definite economic consequencies might be expected. Nevertheless, actual figures on benefit estimations are very sparse.

In an early study, Everetts [26] , as cited by Parmelee, Sullivan and Cerny [27] , made a cooling load analysis of typical buildings in New Orleans, U.S.A. He estimated the share of the total load attributable to the weather, to be 93 % for residence-, 59 % for office buildings and 62 % in case of theaters.

Let's make a speculative attempt. Heating requirements can be considered more weather-dependent than air-conditioning. In this case, residence buildings make the majority. Considering heating and cooling together, let's assume some 80 % as average weather sensitivity. The potential benefit of weather information should be definitly higher than for the construction industry. Hence, even if applying only 2.5 % (Russo, Table 1) and considering 1969 total production figures for Switzerland (Table 3), Fr. 20 million benefit may be expected. Here, the assumption is made, that conditions in New Orleans and Switzerland may be comparable. Considering furthermore, that total costs of weather information given for this industry in 1969 in Switzerland amount to Fr. 50,000, a benefit/cost ratio of 400 can be derived.

Table 3 Estimated benefit for the heating - airconditioning industry in Switzerland by using design weather information.

GNP Production 1969	Fr.	$1,\,000 \cdot 10^6$	GNP of heating plants / Year	Fr.	$600 \cdot 10^6$
Weather Sensitive Portion = 80%	Fr.	$800 \cdot 10^6$	Portion of total radiator costs	Fr.	$200 \cdot 10^6$
			1° C raise of design temperature reduces costs with ∼ 3%		
Potential Benefit = 2, 5% of 80%	Fr.	$20 \cdot 10^6$	effective reduction ∼ 12% (- 15° C ⟶ - 11° C)	Fr.	$24 \cdot 10^6$
Total costs of weather information given	Fr.	$50 \cdot 10^3$	Cost of temperature analysis	Fr.	$40 \cdot 10^3$
Benefit / Cost		400	Benefit / Cost		540

In opposition to this speculation, figures on the right side of the table refer to an actual case. According to engineering calculations, heat consumption may be reduced by about 3 per cent, if increasing winter design temperature by 1° C. Actual analysis of temperature frequencies - at an expense of fr. 40,000 - has shown, however, that winter design temperatures used during the last 30 years may be increased by about 4° C [28] (from - 15° to - 11° C for Zurich). Considering annual production of heating plants in Switzerland and taking into account, that only radiator costs may be reduced by altering design temperature and, that this latter make only about 1/3 of the total production, effective annual saving amounts to 24 million Swiss franks. These figures give a benefit/cost ratio of 540.

It has to be mentioned, that weather information costs of the above kind, are one time costs only, while benefits are generated every year without further expenses. Since, to remove 1 calory of heat costs four times as much as to produce it,one may expect relative benefits for air-conditioning to be greater than shown by the above example for heating.

The question, how to reduce costs, by cheaper insulation, or by a more economical lay-out of the installations (Darvas [29] , Grimm [30] , Glas and Höglund [8] , Robertson [9] , Spencer [10] , Quenzel [31] , and others) is a basic problem of economic analysis of building design (Griffith [32]). Engineers know how costs of insulation and costs of heating depend on the insulation thickness, respectively on the heat transmission coefficient of the walls. They also know, how to minimize total costs by considering the lapse of both these component costs. About the effect of shape design on the reduction of air-conditioning costs experience also exists (e.g. Anson, Kennedy and Spencer [33]). To choose the economically best alternative, to follow an optimum decision making strategy, presupposes however a thourough knowledge on combined probability distributions of the relevant meteorological quantities. Benefit/cost analysis with respect to such significant decisions would probably produce much higher figures than hitherto available estimations.

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