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Principles of Process Controlling of Irrigation Systems Using Queuing Theory

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1. Introduction

The global warming and extreme changes of the environmental conditions are the main themes at the present time. Hot seasons with a minimum amount of rainfall alternate with abnormal rainfall seasons. Each of these extremes negatively undermines the agricultural production, which function of population nourishment is an important part of world economy. From this point of view, the most important part of agricultural production is soil and its ability to create appropriate conditions for growing of cultivated plants. These conditions are formed in an open environment, where we cannot assume an ideal state. The factors which have effect on the process of creating environmental conditions have significant stochastic nature. With this fact must deal those who can ensure sufficient production for the continually increasing demands of nutrition. First of all, the primary opportunity to raise productivity, since the possibilities of agricultural land expansion is limited [1]. The increase has to be achieved by means of various intensification instruments/tools and progressive agricultural technologies such as irrigation, as one of the most intensification tool in agriculture are. The problems of using irrigation systems appear too high investment expenses of irrigation technology and also high overheads.

The expected trend in following periods is significant turnover in question of irrigation as a solution of the current problems. There is also starting sociopolitical pressure with the goal to support the idea of ecologic farming and sustainable development in which irrigation plays its part. That means that irrigation and irrigation technologies will be constantly gaining importance and topicality under the influence of environment. We are expecting a gradual nationwide introduction of new technologies and tools into practice, where the investments are sufficiently profitable, reliable and they will be sufficiently contributing to the expansion of opportunities in agriculture.

2. Material and methods

Irrigation system remains the weakest part of soil management. Ignoring water regime of soil and that of various crops from the beginning to the end of vegetation is a large obstacle for economic and ecological irrigation. Research in the irrigation sector has accumulated enough theoretical and practical knowledge and needs only to look for ways and methods to transfer this know how into irrigation practice as soon as possible [2]. The aim of process observation in the irrigation system is the monitoring and analysis of various factors affecting the growth of crops, depending on the optimum moisture requirements of individual crops, and thus achieves higher productivity per area unit.

Precise irrigation as an aspect of agriculture is just the beginning of the research and represents water application to exact location and at exact dose. Using precise agricultural irrigation management is still in a state development and needs a lot of research and experimental work to define its implementation case study and applicability [3].

We try to integrate the accumulated knowledge into complex unit and then apply existing models and simulations in the experimental conditions, where we compare the efficiency of various algorithms and models of irrigation. By analysing model and its behaviour we expand existing models with new optimization features and compare their results with the original models.

3. Queuing theory basics in irrigation system controlling

Individual factors and associated processes entering into the irrigation system are fully stochastic in nature [4]. Solving problems in this area requires using methods of statistical analysis and mathematical probability. Application discipline for the monitoring and optimisation of the irrigation system is the queuing theory (QT) [5–8].

Queuing theory is dealing with systems, which give us processes of services between customers and service. As a customer in the system of the multiple process can be anything - product, equipment, land's area, etc., that means any element, which is able to satisfy customer's requirements. We can meet with the relations "customer – service" in lots of sectors of the human activities as e.g. traffic, networking etc. [9, 10]. Queuing theory studies mathematical models of systems which elements have stochastic character and where such cases are developed like waiting in queue, delay and consequent loss. Example of such a system is irrigation.

Basic scheme of the queuing system should be describe as follows – customers (service requirements) arrive into the system of service from the source. The service system consists of waiting room, where series of requirements can be developed and from the channels - places of service. When the almost one channel is free, requirement can be served, in the opposite case it is waiting in a queue.

A source can consist of unlimited amount of units – opened system, or final amount of units. After the units have been served they are returned back to the source – closed system.

Units are input into the system from the source in fixed or random time intervals. Process of the input is called **stream of the requirements.** If the moments of input are fixed, deterministic, flow of the requirements is fair. In case of random input, we call the flow of requirements probability according to the distribution process type, which is specified with the sequence of randomly long intervals between two adjacent inputs of requirements. In practice, we can find input flows of requirements Poisson's (exponential), Erlang's, normal, etc.

Input requirement is immediately served, when almost one of channels of service is free. In the opposite case, the request queues up for service. In some cases request leaves the queue following its impatience (e.g. humidity demands of plant do not allow wait for the irrigation dosage).

Mechanism of the service is a process where requests are picked up from the queue to the channels of service. We recognize the following two types of service [11]:

- **Service without priority** – requests are chosen to be served in order of input into the system, according to the rule:
  - "first comes, first served",
  - "last leaves, last served",
- **Service with priority** – requests enter into the system according to the different rules (etc. in the irrigation management, according to the level of loss in the early undelivered irrigation, the priority is assigned to the individual commodities in the crop rotation).

Solution for queuing theory systems with exponential input of the requests and exponential length of service (e.g. Markov's systems or their modification), is not complicated.

Situation is getting more complicated when input processes or services are described by values with different distribution or when the mechanism of service contains other restricted requests with random character. Analytical models of these systems are very complex and many practical situations cannot be mathematically described by using the current analytical tools. In this case, it is better to use simulation models.

Simulation model helps to describe various situations, which can be seen in practical applications of the multiple services; it is not restricted by any requests for distribution of random values and a result of the solution on computer is high amount of practical usable information.

Queuing theory system is widely used within the various production areas and as well as commercial services. Theory is fully processed and results projected on the scientific level and that of agricultural processes. Management of precise irrigation is based on the theoretical principles of queuing theory, where there is an interaction between two sides. On one side, there are channels of service (irrigation system and technological irrigated system) and on the other side there is a group of plants with requirements for moisture [12].

In our research we have created mathematical models of irrigation systems based on theoretical principles of queuing theory [1, 13].

Various combinations of systems based on queuing theory depend on the solution process realised in agricultural practice. Standard QT process in irrigation system is defined as *N*-channel system, limited resource requirements, with a priority system in operation [15]. Where the number of channels of the system is defined as an available pool of technical device of irrigation then source of requirements represent exact determined number of segment area units of agricultural crops and priorities as currently depends on individual segments of moisture in the soil.

In the case of irrigation system the queuing system consists of service channels serving the requests of current plants to supply additional irrigation. If the existing channels are not able to serve immediately the incoming requirements, they leave the system without serving or stay in the waiting queue where they are until the release of a channel selected according to criteria given previously. This priority is necessary in the event of water demand is appearing for those crops which are economically important or in case of non-delivery of irrigation with them causing great economic damage.

Stochastic elements in the case of irrigation system are:

- Input flow of request.
- Time longitude of request service.

Processing current mathematical QT is a complex process that requires the use of computing technology. Optimisation can rationalise the process and thus achieve desired results in agricultural practice.

For this paper we have chosen the model with one channel of service with priority of request where they do not leave the waiting room in the time interval. This model of the process considers an isolated instance where the weight of decision-making is based on a single algorithm determining the priority of requests entering the system. By isolation of algorithms in the right combinations can objectively evaluate the effectiveness of algorithms. Evaluation of the results in this case is judged on the basis of the total time needed for the quantity served exactly the requirements of channel operation (in this case, the technical equipment of mobile irrigation system). Request entering the system are Poisson stream.

The probability of k number of request to time interval t is then determined by:

$$P_k(t) = \frac{(\lambda \cdot t)^k}{k!} \cdot e^{-\lambda \cdot t} \tag{1}$$

where λ is the parameter of arrival of request.

In terms of applications in queuing theory it is essential that the intervals between inputs are exponentially distributed. In terms of the model's practical application there are important characteristics of independence, stationary and ordinary, which determine the conditions under which one is able to use the model with the Poisson distribution.

The time operator is the second important parameter in the queuing system which determines their capacity. There are several factors influencing the service time and therefore it is needed to consider it as an exponentially divided variant with a distribution function:

$$F(t) = 1 - e^{-\frac{t}{t_0}} \tag{2}$$

where t_o is a mean time of service.

Exponential distribution of the time operator assumes that the majority of the operator is realised for a short time. The time longitude of the requirements service depends on several factors. Most interesting cases arise if the time of service depends on a long waiting queue.

4. Algorithm system and evaluation of priorities

Algorithm of decision-making process is based on priority testing. Individual test algorithms for the priority requests determination in series are based on the template for test algorithm. Each template as the below stated test example, has to fulfil requirements for efficient data processing.

Each incoming request gets to „waiting room“ as the output value of the priority algorithm in the range of 1–100 points which is the total average of the individual tests. The value of 100 means the highest priority. The request in waiting room is placed in queue according to its priority. In the waiting room there is scheduled control mechanism that controls the request duration in a waiting room. The mechanism is changing the current priority of requirements depending on the complexity, the importance of technical crops, etc.

Heuristic analysis of the individual tests consists of following elements:

- Relationship analysis of final calculation of the given priority test.
- Composition of efficient data sections for efficient achievement for each test.

- Composition of final test procedure.
- To identify complexity of evaluated test.

Heuristic elements of the individual actions:

- Defined relation and complexity of calculation,
- Heuristic supervision of required data set from database,
- Views on the data set to obtain required sample for the relationship,
- To identify complexity of achievement for test control.

Heuristic analysis is achieved with exact definition of needed data set that is data-mining from database. This set of heterogeneous data is connected on the level of data section in SQL machine to the usable units for given calculation. By the following view on data from the right direction, we are identifying variable parameter of calculation entering into the relation for calculation. The developed database and application platform for test algorithms gives possibility to use all heuristic methods to priority test.

Calculation itself is running on the selected set of agronomical equations. Individual formulas are coming out from the previous studies and recommended methods of applied irrigation.

5. Model of priority determination in process control

We are verifying the model example QT of the controlled irrigation type G/D/1 for integrity of proposed system for efficient evaluation. It is used for function verification of the decision-making system. We identify randomly generated flow of requests, created on the selected sets of measured segments. We are monitoring system behaviour for priorities selection. We determined basic tests of priority to choose the sequence in series of requests. For simplification we are thinking about exclusive channel of the service, incoming requests in deterministic cycle and interval of requests in cycles. We choose variable sets of cycle in each measurement. We are performing process for three model situations with the same sample of definition data according to criteria of rainfall template:

- Model of the extremely dry cycle.
- Model of dry cycle.
- Wet cycle.

Evaluation of the 6. model solution

Model solution is offering integrated view on application of the efficient information processing with the use of heuristics. Model solution shows integrity of the proposed solution suitable for put it into the real application with real data. Main target was to verify the individual parts functionality for input and output, connection to the heuristic tests and running of information processing by heuristic system. In the output table of very dry cycle is the result sample of irrigation process of individual segments. Result from the table is that system with one channel of service is in very dry season undersized, and become to the increasing of series of requests and ignorance of duplicated requests.

Series of input requests is dynamically changed by each cycle. Significant are some swings by the given generator. Request after serving is returning back to the series of requests with high priority. This is a result of necessity for tune of sorter in the series of requests. Based on empiric tests we propose additionally to increase priority of requests based on duration for each actualisation of series of requests so in the undersized system of service does not come to the permanent irrigation only selected economically important crops.

7. Conclusion

Agricultural land is a huge reservoir of water whose amount can be calculated from known values of hydro limits for different types of agricultural land in the Slovakia and for soils with different depth of soil profile. In this environment uneven distribution of rainfall and other water balance components are reflected; which significantly affects the amount of physiologically active water in time and space, as well as its dynamics in the retention area of the country.

The accurate irrigation as an aspect of precise agriculture is currently at beginning of its research and it describes the application of water in the exact place and exact dose. Using precise agriculture for irrigation management is still under development and more research and experimental work needs to be done in order to define its feasibility and applicability. Utilisation of principles of queuing theory system in the regulation of irrigation has its justification. Identification of priority requests by the system of modified tests ensures high variation usage in real conditions. Simulations are showing to the high precision of this type of decision making without having an impact of human factor. Real applications of algorithms based on the QTS, testify about contribution of this regulation model in the area of random variable parameters in time.

The expected trend in near future is a significant turnover in irrigation outlook as possible solution of the current problems. Some intensification tools have achieved a roof effect and therefore producers are looking for sub-options.

Utilisation of principles of queuing theory system in the managed irrigation is improving. Identification of priority requests by means of modified tests helps high variability usage in real conditions. Simulations are showing with the high accuracy that this type of decision-making is without impact of human factor. Real applications of decision making algorithms based on the QT and contribution of this developed model in the area of random variable parameters will be receiving increasing attention.

The expected trend in near future is a significant turnover in irrigation prospect as possibility of solving the current problems. Some intensification tools have achieved maximal effect and therefore producers are looking for other options.

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Zasady procesu sterowania systemami nawadniającymi w oparciu o teorię kolejkowania

Streszczenie

Wielkość i stabilność plonów z hektara upraw rolnych w dużym stopniu zależy od warunków klimatycznych, temperatury, promieniowania słonecznego, ale przede wszystkim ilości i jakości opadów, które dla większości upraw rolnych są niewystarczające. Pomimo faktu, że sztuczne nawadnianie ma tendencję wzrostową w ostatnich latach, budowanie systemów nawadniających jest trudne pod względem inwestycji, jak również kosztowne. Jeśli pojemność systemu nawadniania, jest niewystarczające, koszty inwestycji są zbyt wysokie, a system nie zawsze będzie w stanie spełnić zapotrzebowanie na wymaganym prawdopodobieństwem aby sprostać wymaganiom wynikającym na dostawy dodatkowego nawadniania. Spowoduje to zmniejszenie wydajności upraw rolnych lub, w skrajnym przypadku może doprowadzić do uniknięcia szkód w uprawach. Jeśli pojemność obiektu nawadniania musi zostać zmieniona to będzie oznaczać niepotrzebnie wysokie koszty inwestycyjne i ilość urządzeń nawadniających nie zawsze będzie dostatecznie wykorzystywana. Te dwa przy-

padki graniczne nie dają optymalnego wykorzystania i budowy urządzeń do prac irygacyjnych. Roszczenia plonów często nie emanują z zestawu pewnych roszczeń z tytułu każdej z roślin, ale są tylko szacunki oparte na empirycznych doświadczeniach. Precyzyjne ustalenie tych danych jest bardzo trudne i bez użycia dokładnych metod matematycznych i informatyki byłoby praktycznie niemożliwe. Niniejszy artykuł poświęcony jest tworzeniu modeli, które pozwoliłyby na ustalenie optymalnej wydajności systemu nawadniania w odniesieniu do upraw i urządzeń nawadniających. Rozwiązanie na średnią i dużą skalę nawadniania nie jest możliwe efektywne i precyzyjne za pomocą tradycyjnych metod, bez użycia aparatu matematycznego, modelowania, metody symulacji rozdzielczości i oczywiście, bez wykorzystania nowoczesnej technologii komputerowej. Jeśli spojrzymy na proces nawadniania od systemowego punktu widzenia, cały system nawadniania można podzielić na dwie części – rośliny, które otrzymują nawadniania i system, który dostarcza nawadniania. System nawadniania i upraw nawadnianych są w procesie sztucznego nawilżania będącego dostawcą i klientem. Konieczność wilgotność dla roślin występuje jako wymogu określonego rodzaju operatora - dostaw koniecznych ilościach nawadniania uzupełniających. System nawadniania jest jak stacja paliw, która spełnia wymagania - nawadnianie zapewnia, lub nie, jeśli pojemność nie jest wystarczająco wysoka. W związku z tym, problem determinacji systemu pojemności nawadniania może być postrzegany jako problem teorii kolejek – podmiot ze środków wprowadzonych do systemu w odstępach stałych lub losowo. W naszym przypadku, przepisów wjazdowych rośliny są w przypadkowych odstępach czasu. Po wejściu do operatora systemu urządzenie pracuje na natychmiast, jeśli jest co najmniej jeden wolny kanał. W przeciwnym razie wniosek może zostać stracony. Do stworzenia modelu do wyznaczania optymalnej wydajności systemu nawadniania, musimy znaleźć odpowiedzi na te pytania: co to jest średnia długość kolejki, co jest oczekiwana średnia liczba jednocześnie nawadnianych akrów, co jest oczekiwana średnia liczba hektarów nie wymagają nawadniania, co jest spodziewane niewykorzystane moce systemów nawadniających, jaki jest średni czas oczekiwania w kolejce i to, co jest średnia liczba wymagań zawartych w systemie.