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Vision

Achieving leadership, excellence and innovation in the field of open learning, community service, and scientific research, in addition to reinforcing the University leading role in establishing a Palestinian society built on knowledge and science.

Mission

To prepare qualified graduates equipped with competencies that enable them to address the needs of their community, and compete in both local and regional labor markets. Furthermore, The University seeks to promote students' innovative contributions in scientific research and human and technical capacity-building, through providing them with educational and training programs in accordance with the best practices of open and blended learning approach, as well as through fostering an educational environment that promotes scientific research in accordance with the latest standards of quality and excellence. The University strives to implement its mission within a framework of knowledge exchange and cooperation with the community institutions and experts.

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- Partnership with the community
- Participative management.
- Enforcing the pioneer role of women.
- Integrity and Transparency.
- Competitiveness.

The Journal

The Palestinian Journal of Technology and Applied Sciences is an annual scientific refereed journal, issued by the Deanship of Graduate Studies and Scientific Research. The first issue of the Journal was published in January 2018 after obtaining an International Standard Serial Number (E- ISSN: 2521-411X), (P– ISSN: 2520-7431).

The journal publishes original research papers and studies conducted by researchers and faculty staff at QOU and by their counterparts at local and overseas universities, in accordance with their academic specializations. The Journal also publishes reviews, scientific reports and translated research papers, provided that these papers have not been published in any conference book or in any other journal.

The Journal comprises the following topics:

Information and Communication Technology, Physics, Chemistry, Biology, Mathematics, Statistics, Biotechnology, Bioinformatics, Agriculture Sciences, Geology, Ecology, Nanotechnology , Mechatronics, Internet of things , Artificial Intelligence and Big Data.

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First: Requirements of preparing the research:

The research must include the following:

1. A cover page which should include the title of the research stated in English and Arabic, including the name of researcher/researchers, his/her title, and email.
2. Two abstracts (English and Arabic) around (150-200 word). The abstract should include no more than 6 key words.
3. Graphs and diagrams should be placed within the text, serially numbered, and their titles, comments or remarks should be placed underneath.
4. Tables should be placed within the text, serially numbered and titles should be written above the tables, whereas comments or any remarks should be written underneath the tables

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1. The Researcher should submit a letter addressing the Head of Editorial Board in which he/she requests his paper to be published in the Journal, specifying the specialization of his/her paper.
2. The researcher should submit his research via email to the Deanship of Scientific research (tas@qou.edu) in Microsoft Word Format, taking into Consideration that the page layout should be two columns.

   (Check the attached digital form on the website of the Journal)
3. The researcher should submit a written pledge that the paper has not been published nor submitted for publishing in any other periodical, and that it is not a chapter or a part of a published book.
4. The researcher should submit a short Curriculum Vitae (CV) in which she/he includes full name, workplace, academic rank, specific specialization and contact information (phone and mobile number, and e-mail address).
5. Complete copy of the data collection tools (questionnaire or other) if not included in the paper itself or the Annexes.
6. No indication shall be given regarding the name or the identity of the researcher in the research paper, in order to ensure the confidentiality of the arbitration process.

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14. Researchers must commit to pay the expenses of the arbitration process, in case of withdrawal during the final evaluation process and publication procedures.
15. The researchers will be notified of the results and final decision of the editorial board within a period ranging from three to six months starting from the date of submitting the research.

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1. Footnotes should be written at the end of the paper as follows; if the reference is a book, it is cited in the following order, name of the author, title of the book or paper, name of the translator if any or reviser, place of publication, publisher, edition, year of publishing, volume, and page number. If the reference is a journal, it should be cited as follows, author, paper title, journal title, journal volume, date of publication and page number.
2. References and resources should be arranged at the end of the paper in accordance to the alphabetical order starting with the surname of author, followed by the name of the author, title of the book or paper, place of publishing, edition, year of publication, and volume. The list should not include any reference which is not mentioned in the body of the paper.
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   - In case the publishing date is missing , the researcher writes (N.D)
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   http://journals.qou.edu/recources/pdf/apa.pdf

Five: Peer Review & Publication Process:

All research papers are forwarded to a group of experts in the field to review and assess the submitted papers according to the known scientific standards. The paper is accepted after the researcher carries out the modifications requested. Opinions expressed in the research paper solely belong to their authors not the journal. The submitted papers are subject to initial assessment by the editorial board to decide about the eligibility of the research and whether it meets the publication guidelines. The editorial board has the right to decide if the paper is ineligible without providing the researcher with any justification.

The peer review process is implemented as follows:

1. The editorial board reviews the eligibility of the submitted research papers and their compliance with the publication guidelines to decide their eligibility to the peer review process.
2. The eligible research papers are forwarded to two specialized Referees of a similar rank or higher than the researcher. Those Referees are chosen by the editorial board in a confidential approach, they are specialized instructors who work at universities and research centers in Palestine and abroad.
3. Each referee must submit a report indicating the eligibility of the research for publication.
4. In case the results of the two referees were different, the research is forwarded to a third referee to settle the result and consequently his decision is considered definite.
5. The researcher is notified by the result of the editorial board within a period ranging from three to six months starting from the date of submission. Prior to that, the researcher has to carry out the modifications in case there are any.
6. The researcher will receive a copy of the journal in which his/her paper was published, as for researchers from abroad, a copy of the Journal volume will be sent to the liaison university office in Jordan and the researcher in this case will pay the shipping cost from Jordan to his/her place of residency.

Six: Scientific Research Ethics:

The researcher must:

1. Commit to high professional and academic standards during the whole process of conducting research papers, from submitting the research proposal, conducting the research, collecting data, analyzing and discussing the results, and to eventually publishing the paper. All must be conducted with integrity, neutralism and without distortion.

2. Acknowledge the efforts of all those who participated in conducting the research such as colleagues and students and list their names in the list of authors, as well as acknowledging the financial and morale support utilized in conducting the research.
3. Commit to state references soundly, to avoid plagiarism in the research.
4. Commit to avoid conducting research papers that harm humans or environment. The researcher must obtain in advance an approval from the University or the institutions he/she works at, or from a committee for scientific research ethics if there is any, when conducting any experiments on humans or the environment.
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1. The editorial board confirms its commitment to the intellectual property rights
2. Researchers also have to commit to the intellectual property rights.
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6. The author has the right to request the accreditation of the published papers to himself.

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No. 3

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استقرار حلّ المعادلة الموجية غير المتجانسة بمفهوم هيريس ـ أولام ـ راسيس

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Abstract:

In this paper, we apply the Duhamel's Principle to prove the Hyers-Ulam-Rassias stability for one-dimensional inhomogeneous wave equation on an infinite homogeneous string with zero initial conditions. We have also established the Hyers-Ulam-Rassias stability of nonzero initial value problem of the inhomogeneous wave equation for an infinite string. Some illustrative examples are given.

Keywords: Hyers-Ulam-Rassias Sability, Wave Equation, Duhamel's Principle.

ملخص:

في هذا البحث، استخدم الباحث مبدأ ديوهامل لإثبات استقرار بمعنى هيريس–أولام–راسيس لحلّ المعادلة الموجية غير المتجانسة عبر وتر متجانس ولا نهائي، عندما تكون الشروط الابتدائية صفرية. ولقد أثبت أيضًا الاستقرار للمعادلة الموجية غير المتجانسة عبر وتر متجانس ولا نهائي، عندما تكون الشروط الابتدائية غير صفرية. وجرى دعم النتائج ببعض الأمثلة التوضيحية.

الكلمات المفتاحية: الاستقرار بمفهوم هيريس–أولام–راسيس، المعادلة الموجية، مبدأ ديوهامل.

1- Introduction and Preliminaries

The study of stability problems for various functional equations originated from a famous talk given by Ulam in 1940. In the talk, Ulam discussed a problem concerning the stability of homomorphisms. A significant breakthrough came in 1941, when Hyers [1] gave a partial solution to Ulam's problem. After that and during the last two decades, a great number of papers have been extensively published concerning the various generalizations of Hyers result .(see [2-10]).

Alsina and Ger [11] were the first mathematicians who investigated the Hyers-Ulam stability of the differential equation $g' = g$. They proved that if a differentiable function $y : I \to R$ satisfies $|y' - y| \le \varepsilon$, $\varepsilon > 0$, for all $t \in I$, then there exists a differentiable function $g : I \to R$ satisfying $g'(t) = g(t)$ for any $t \in I$ such that $|g - y| \le 3\varepsilon$, for all $t \in I$. This result of Alsina and Ger has been generalized by Takahasi et al [12] to the case of the complex Banach space valued differential equation $y' = \lambda y$.

Furthermore, the results of Hyers-Ulam stability of differential equations of first order were also generalized by Miura et al. [13], Jung [14] and Wang et al. [15].

Gordji et al. [16] generalized Jung's result to first order and second order nonlinear partial differential equations. Lungu and Craciun [17] established results on the Ulam-Hyers stability and the generalized Ulam-Hyers-Rassias stability of nonlinear hyperbolic partial differential equations. Jung [18], Choi and Jung [19] had used coordination substitution way and respectively, the method of a kind of dilation invariance to prove the generalized Hyers-Ulam stability of wave equation. E. Biçer [20] applied Laplace transform technique to establish the Hyers-Ulam stability for the wave equation.

In this paper we consider the Hyers-Ulam-Rassias stability of the nonhomogeneous

wave equation

$$\frac{\partial^2 u}{\partial t^2} = a^2 \frac{\partial^2 u}{\partial x^2} + g(x,t) \quad 0 < t < \infty, \quad -\infty < x < \infty, \tag{1.1}$$

with zero initial condition

$$u(x,0) = 0, \quad u_t(x,0) = 0, \tag{1.2}$$

where $u(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$.

Moreover we have proved sufficient conditions for Hyers-Ulam-Rassias stability of the inhomogeneous wave equation

$$\frac{\partial^2 u}{\partial t^2} = a^2 \frac{\partial^2 u}{\partial x^2} + g(x,t), \quad 0 < t < \infty, \quad -\infty < x < \infty \tag{1.3}$$

with nonzero initial condition

$$u(x,0)=\alpha(x),\ u_t(x,0)=\beta(x),\ -\infty<x<\infty \qquad (1.4)$$

where $u(x,t)\in C^2[\mathbb{R}\times(0,\infty)], \alpha(x)\in C^2(\mathbb{R}^1)$, and $\beta(x)\in C^1(\mathbb{R}^1)$.

Definition 1 [21] We will say that the equation (1.1) has the Hyers-Ulam-Rassias (HUR) stability if there exists $K>0$, $\varphi(x,t):\mathbb{R}\times\mathbb{R}\to\mathbb{R}$ and for each solution $u(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the inequality

$$|\ u_{tt}-a^2u_{xx}-g(x,t)\ |\le\varphi(x,t)$$

with the initial condition (1.2) then there exists a solution $w(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the equation (1.1) such that $|\ u(x,t)-u_0(x,t)\ |\le K\varphi(x,t)\ ,\ \forall(x,t)\in\mathbb{R}\times(0,\infty)$, where K is a constant that does not depend on φ nor on $u(x,t)$, and $\varphi(x,t)\in C(\mathbb{R}\times(0,\infty))$.

Definition 2 [21] We will say that the equation (1.3) has the Hyers-Ulam-Rassias (HUR) stability with respect to $\varphi>0$, if there exists $K>0$ such that for each $\varepsilon>0$ and for each solution $u(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the inequality

$$|\ u_{tt}-a^2u_{xx}-g(x,t)\ |\quad\le\varphi(x,t)$$

with the initial condition (1.4) then there exists a solution $w(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the equation (1.3) such that $|\ u(x,t)-u_0(x,t)\ |\le K\phi(x,t)\ ,\ \forall(x,t)\in\mathbb{R}\times(0,\infty)$, where K is a constant that does not depend on φ nor on $u(x,t)$, and $\phi(x,t)\in C(\mathbb{R}\times(0,\infty))$.

Now, to motivate the Duhamel method for stability of the infinite homogeneous string in the sense of Hyers-Ulam-Rassias we will consider the following related problem

$$\frac{\partial^2 v}{\partial t^2}=a^2\frac{\partial^2 v}{\partial x^2}\ ,\quad t>s,\ -\infty<x<\infty \qquad (1.5)$$

with initial condition

$$v(x,s;s)=0,\ v_t(x,s;s)=g(x,s) \qquad (1.6)$$

where $v(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$.

Now, notice that the problem (1.5),(1.6) has initial conditions prescribed at arbitrary time $t=s$, rather than at $t=0$. Thus we can rewrite $v(x,t;s)=w(x,t-s;s)$ where $w(x,t-s;s)$ solves the problem

$$\frac{\partial^2 w}{\partial t^2}=a^2\frac{\partial^2 w}{\partial x^2}\ ,\quad t>s,\ -\infty<x<\infty \qquad (1.7)$$

with initial condition

$$w(x,0;s)=0,\ w_t(x,0;s)=\ g(x,s) \qquad (1.8)$$

where $w(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$.

(Duhamel's Principle for the wave equation (1.1), see [22]) If $g(x,t)\in C^1(\mathbb{R})$ in x and $C^0(0,\infty)$ in t, then

$$u(x,t)=\int_0^t v(x,t;s)ds=\int_0^t w(x,t-s;s)ds$$

$$=\frac{1}{2a}\int_0^t\int_{x-a(t-s)}^{x+a(t-s)} g(r,s)drds \qquad (1.9)$$

2. On Hyers-Ulam-Rassias Stability for Inhomogeneous Wave Equation

First consider the HUR stability of the IV problem (1.3),(1.4) of forced vibrations of a homogeneous infinite string with zero initial conditions.

Theorem1.1 If $v(x,t.;s)\in C^2[\mathbb{R}\times(0,\infty)]$, solves the homogeneous problem (1.7),(1.8), $u(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$ and there is a function $\varphi(x,t):\ \mathbb{R}\times\mathbb{R}\to\mathbb{R}^+$, such that

$$\int_0^t\int_0^s\varphi(x,y)dyds\le K\varphi(x,t) \qquad (2.1)$$

then the IV inhomogeneous problem (1.1),(1.2) is stable in the sense of HUR.

Proof. Let $\varphi(x,t) > 0$ and $u(x,t)$ be an approximate solution of the IV problem (1.1),(1.2)

We will show that there exists a function $u_0(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ satisfying the equation (1.1) and the initial condition (1.2) such that

$$| u(x,t) - u_0(x,t) | \leq K\varphi(x,t)$$

For (1.1) let consider the inequality

$$-\varphi(x,t) \leq \frac{\partial^2 u}{\partial t^2} - a^2 \frac{\partial^2 u}{\partial x^2} - g(x,t) \quad \leq \varphi(x,t) \tag{2.2}$$

Since $u(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$, we integrate (2.2) with respect to t, to obtain

$$-\int_0^t \varphi(x,s)ds \leq u_t(x,t) - u_t(x,0) - \int_0^t g(x,s)ds - a^2 \int_0^t u_{xx}(x,s)ds$$
$$\leq \int_0^t \varphi(x,s)ds \tag{2.3}$$

By virtue of (1.9) and the initial condition (1.8), we have

$$-\int_0^t \varphi(x,s)ds \leq u_t(x,t) - \int_0^t w_t(x,0,s)ds - a^2 \int_0^t \int_0^s w_{xx}(x,t-s,s)ds$$
$$\leq \int_0^t \varphi(x,s)ds$$

Or, equivalently

$$-\int_0^t \varphi(x,s)ds < u_t(x,t) - \int_0^t w_t(x,0;s)ds - \int_0^t \int_0^s w_{tt}(x,t-s;s)ds$$
$$\leq \int_0^t \varphi(x,s)ds \tag{2.4}$$

Since

$$\frac{\partial}{\partial t} \int_0^t \int_0^s w_t(x,t-s;y)dyds = \int_0^t w_t(x,0;s)ds + \int_0^t w_{tt}(x,t-s;s)ds \tag{2.5}$$

Then by integrating the inequality (2.4) and using (2.1) we get

$$-C\varphi(x,t) < -\int_0^t \int_0^s \varphi(x,y)dyds \quad < u(x,t) - u(x,0) - \int_0^t \int_0^s w_t(x,t-s;y)dyds$$
$$\leq \int_0^t \int_0^s \varphi(x,y)dyds \leq C\varphi(x,t),$$

Use the initial conditions (1.2),(1.8) to obtain

$$-C\varphi(x,t) \leq u(x,t) - \int_0^t w(x,t-s;s)ds \leq C\varphi(x,t), \tag{2.6}$$

Now, we show that

$$u_0(x,t) = \int_0^t w(x,t-s;s)ds \tag{2.7}$$

satisfies the problem (1.1),(1.2). Indeed Since $w(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$, we differentiate twice, successively with respect to t in order to obtain

$$\frac{\partial}{\partial t} u_0(x,t) = w(x,0;s) + \int_0^t w_t(x,t-s;s)ds = \int_0^t w_t(x,t-s;s)ds \tag{2.8}$$

and

$$\frac{\partial u_{tt}(x,t)}{\partial t} = w_t(x,0;t) + \int_0^t w_{tt}(x,t-s;s)ds$$
$$= g(x,t) + a^2 u_{xx}(x,t),$$

this shows that $u(x,t)$ is a solution of (1.1). The equations (2.7),(2.8) yield $u_0(x,0) = 0$ and $u_t(x,0) = 0$, respectively

By D'Alembert formula, the solution of the problem (1.7), (1.8) is given by

$$w(x,t) = \frac{1}{2a} \int_{x-at}^{x+at} g(r,s)ds \tag{2.10}$$

Hence

$$u_0(x,t) = \int_0^t w(x,t-s;s)ds = \frac{1}{2a} \int_0^t \int_{x-a(t-s)}^{x+a(t-s)} g(r,s)drds \tag{2.11}$$

From (2.6) and (2.7) we infer that the IV problem (1.1), (1.2) is stable in the sense of HUR.

To illustrate the obtained results we give the following example.

Example 2.1 Let the following IV problem be given

$$u_{tt} - u_{xx} = 0 \qquad (2.12)$$

$$u(x,0) = 0,\ u_t(x,0) = 0 \qquad (2.13)$$

To establish the HUR stability let consider the inequality

$$-\varphi(x,t) \le u_{tt} - u_{xx} - x + t \le \varphi(x,t) \qquad (2.14)$$

Integrating (2.14) successively twice with respect to t, the last inequality yield

$$-C\varphi(x,t) \le u(x,t) - \int_0^t \int_0^s u_t(x,t-y;y)\,dyds \le C\varphi(x,t), \qquad (2.15)$$

or

$$-C\varphi(x,t) \le u(x,t) - \int_0^t \int_0^s (x-y)\,dyds \le C\varphi(x,t), \qquad (2.16)$$

One can show that

$$u_0(x,t) = \int_0^t \int_0^s (x-y)\,dyds = \frac{1}{2}t^2 x - \frac{1}{6}t^3 \qquad (2.17)$$

is a solution of (2.12),(2.13).

Now if we let

$$\varphi(x,t) = e^{x+t}, \qquad (2.18)$$

then from (2.16) and (2.18), we get

$$-C\int_0^t \int_0^s e^{x+t}\,dydt \le u(x,t) - \int_0^t \int_0^s (x-y)\,dyds \le C\int_0^t \int_0^s e^{x+t}\,dydt \qquad (2.19)$$

Or, equivalently letting $C = 1$ and putting the result

$$\int_0^t \int_0^s e^{(x+s)}\,dydt = e^x\left(e^t - t - 1\right) \le e^{x+t},\ \forall t \in (0,\infty)$$

in (2.19), we have

$$-e^{x+t} \le u(x,t) - \frac{1}{2}t^2 x - \frac{1}{6}t^3 \le e^{x+t} \qquad (2.20)$$

Hence, the IV problem (2.12), (2.13) is stable in the sense of HUR.

Now we will consider the HUR stability of the IV problem (1.1), (1.2) of forced Vibrations of a homogeneous infinite string with nonzero initial conditions. For this purpose, we consider the following related problems for stability of the infinite homogeneous string in the sense of HUR.

$$\frac{\partial^2 v}{\partial t^2} = a^2 \frac{\partial^2 v}{\partial x^2},\quad t > s,\ -\infty < x < \infty \qquad (2.21)$$

with initial condition

$$v(x,s;s) = 0,\ v_t(x,s;s) = g(x,s) \qquad (2.22)$$

where $v(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$.

Now, notice that the problem (2.21),(2.22) has initial conditions given at arbitrary time $t = s$, instead of at $t = 0$. Thus we can rewrite $v(x,t;s) = w(x,t-s;s)$ where $w(x,t-s;s)$ solves the problem

$$\frac{\partial^2 w}{\partial t^2} = a^2 \frac{\partial^2 w}{\partial x^2},\quad t > s,\ -\infty < x < \infty \qquad (2.23)$$

with initial condition

$$w(x,0;s) = 0,\ w_t(x,0;s) = g(x,s) \qquad (2.24)$$

where $w(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$. Now, let $\mu(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ be a solution of IV Problem

$$\frac{\partial^2 \mu}{\partial t^2} = a^2 \frac{\partial^2 \mu}{\partial x^2},\quad t > s,\ -\infty < x < \infty \qquad (2.25)$$

with initial condition

$$\mu(x,0;s) = \alpha(x),\ \mu_t(x,0;s) = \beta(x) \qquad (2.26)$$

If $\phi(x,t;s) \in C^2[\mathbb{R} \times (0,\infty)]$, solves the homogeneous problem (2.25),(2.26) and $\varphi(x,t): \mathbb{R} \times \mathbb{R} \to \mathbb{R}^+$, such that

$$\int_0^t \int_0^s \varphi(x,y)\,dyds \le K\varphi(x,t)$$

then the IV inhomogeneous problem (1.3),(1.4) is stable in the sense of HUR.

Proof. Let $\varphi(x,t) > 0$ and $u(x,t)$ be an approximate solution of the IV problem (1.3),(1.4). We will show that there exists a function $u_0(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ satisfying the equation (1.3) and the initial condition (1.4) such that

$$|u(x,t) - u_0(x,t)| \le K\varphi(x,t)$$

First we make a substitution $u(x,t) = \mu(x,t) + w(x,t)$, where $\mu(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ is a solution of IVP (2.25),(2.26).

Consider the following inequality associated with Eq. (1.3)

$$-\varphi(x,t) \le \frac{\partial^2 u}{\partial t^2} - a^2\frac{\partial^2 u}{\partial x^2} - g(x,t) \le \varphi(x,t) \tag{2.27}$$

By integration (2.27) with respect to t, we have

$$-\int_0^t \varphi(x,s)ds \le u_t(x,t) - u_t(x,0) - \int_0^t g(x,t)ds - a^2\int_0^t u_{xx}(x,t)ds$$

$$\le \int_0^t \varphi(x,s)ds \tag{2.28}$$

By using (2.28) and the substitution

$$u(x,t) = \mu(x,t) + w(x,t), \tag{2.29}$$

we obtain

$$-\int_0^t \varphi(x,s)ds \le u_t(x,t) - \mu_t(x,0) - \int_0^t w_t(x,0;s)ds - \int_0^t \mu_t(x,s)ds$$

$$-\int_0^t\int_0^s w_{tt}(x,t-y;y)dyds \le \int_0^t \varphi(x,s)ds \tag{2.30}$$

Now, in view of the following

$$\frac{\partial}{dt}\left[\int_0^t \mu_t(x,s)ds + \int_0^t\int_0^s w_t(x,t-s;y)dyds\right]$$

$$= \mu_t(x,0;s) + \int_0^t \mu_t(x,s)ds + \int_0^t w_t(x,0;s)ds + \int_0^t\int_0^s w_{tt}(x,t-s;s)ds$$

we get

$$-C\varphi(x,t) \le -\int_0^t\int_0^s \varphi(x,y)dyds \le u(x,t) - u(x,0) - \int_0^t \mu_t(x,s)ds$$

$$-\int_0^t\int_0^s w_t(x,t-y;y)dyds \le \int_0^t\int_0^s \varphi(x,y)dyds \le C\varphi(x,t)$$

Using (2.30) and (2.29) it follows that

$$-C\varphi(x,t) \le u(x,t) - \mu(x,0;s) - w_t(x,0;s) - \int_0^t \mu_t(x,s)ds$$

$$-\int_0^t\int_0^s w_t(x,t-s;s)dsdt \le C\varphi(x,t),$$

Now, we show that

$$u_0(x,t) = \int_0^t \mu_t(x,s)ds + \int_0^t w(x,t-s;s)ds =$$

$$= \mu(x,t) + \int_0^t w(x,t-s;s)ds \tag{2.31}$$

satisfies the problem(1.3),(1.4). Indeed Since $u_0(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$, we differentiate twice (2.31), successively with respect to t to obtain

$$\frac{\partial}{\partial t}\left[\int_0^t w(x,t-s;s)ds + \mu(x,t)\right] = w(x,0;t) + \int_0^t w_t(x,t-s;s)ds + \mu_t(x,t)$$

$$= \int_0^t w_t(x,t-s;s)ds + \mu_t(x,t) \tag{2.32}$$

and

$$\frac{\partial^2}{\partial t^2}\left[w(x,0;t) + \int_0^t w_t(x,t-s;s)ds + \mu_t(x,t)\right]$$

$$= w_t(x,0;t) + \int_0^t w_{tt}(x,t-s;s)ds + \mu_{tt}(x,t)$$

$$= g(x,t) + w_{tt}(x,t) + \mu_{tt}(x,t) = g(x,t) + a^2 u_{xx}$$

This shows that $u_0(x,t)$ is a solution of (1.3). From (2.32) and the initial condition (2.26) it follows that $u_0(x,0)=\alpha(x)$ and $u_t(x,0)=\beta(x)$, respectively.

By virtue of (2.31) and applying D' Alembert formula to (2.25) and (2.26), the solution of equation (1.3) is given by

$$u_0(x,t)=\frac{1}{2}\left[\alpha(x+at)+\beta(x+at)\right]+\frac{1}{2a}\int_{x-at}^{x+at}\beta(s)ds$$

$$+\frac{1}{2a}\int_0^t\int_{x-a(t-s)}^{x+a(t-s)}g(r,s)drds \qquad (2.33)$$

Therefore, the solution (2.33) of the IV problem (1.3),(1.4) is stable in the sense of HUR.

Example 2.2 Let be given

$$u_{tt}-u_{xx}=x-t \qquad (2.34)$$

$$u(x,0)=x,\ u_t(x,0)=1-2x \qquad (2.35)$$

Applying the same argument used in Theorems 2.1,2.3 we obtain

$$u_0(x,t)=\int_0^t w(x,t-s;s)ds+\mu(x,s)$$

where

$$\int_0^t w(x,t-s;s)ds=\int_0^t\int_0^s(x-y)dyds=\frac{1}{2}t^2x-\frac{1}{6}t^3$$

is the solution equation (2.34) with corresponding zero initial conditions

$$u(x,0)=0,\ u_t(x,0)=0$$

and

$$\mu(x,t)=x+(1-2x)t$$

is a solution of IV Problem

$$\frac{\partial^2\mu}{\partial t^2}=a^2\frac{\partial^2\mu}{\partial x^2},\ t>0,\quad -\infty<x<\infty$$

with initial condition

$$\mu(x,0;s)=x,\ \mu_t(x,0;s)=1-2x$$

Then by (2.30), we have the solution of IV Problem (2.34),(2.35)

$$u_0(x,t)=x+(1-2x)t+\frac{1}{2}t^2x-\frac{1}{6}t^3$$

One can easily verify that initial condition(2.39) satisfies.

Now let $\varphi(x,t)=e^{x+t}$, then from (2.16),with $C=1$, we get

$$-e^{x+t}\le-\int_0^t\int_0^x e^{x+t}dydt\le u(x,t)-x-(1-2x)t-\frac{1}{2}t^2x+\frac{1}{6}t^3$$

$$\le\int_0^t\int_0^x e^{x+t}dydt\le e^{x+t} \qquad (2.36)$$

By differentiating the inequality (2.36) twice with respect to t, we find

$$-e^{x+t}\le u_{tt}(x,t)-(x-t)\le e^{x+t} \qquad (2.37)$$

Therefore, the inequalities (2.36),(2.37) that the IV problem (2.34),(2.35) is stable in the

Therefore, the inequalities (2.36), (2.37) that the IV problem (2.34),(2.35) are stable in the sense of HUR.

Remark It should be noted here that it follows easily that the solutions (2.11), (2.33) are unique.

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An Efficient Anchor Nodes Distribution for Accurate Localization (EDAL) in Mobile Wireless Sensor Networks

توزيع نقاط الربط (المرساة) في شبكات الاستشعار اللاسلكية المتنقلة من أجل توطين دقيق (EDAL)

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Abstract:

The velocity parameter in mobile Wireless Sensor Networks (WSNs) is a critical factor in anchor nodes distribution. However, most of the previous schemes use the random velocity to transmit anchor nodes as in the waypoint mobility model, which produces a considerable overlap between anchor nodes without improving the localization accuracy. In this paper, we improve such model by controlling the anchor node velocity. In the proposed scheme (EDAL), the anchor node velocity is a function of the overlap degree between anchor nodes and number of anchor node in the neighbor. Thus, EDAL can distribute the anchor nodes efficiently to improve the localization accuracy and expand the coverage area simultaneously. We evaluate the EDAL performance through extensive simulation experiments.

Keywords: Wireless Sensor Networks, Waypoint Model.

ملخص:

تعد معلمة السرعة في شبكات الاستشعار اللاسلكية المتنقلة (WSNs) عاملاً هامًا في توزيع نقاط الربط (المرساة)، معظم المخططات السابقة تستخدم السرعة العشوائية لإرسال نقاط الربط كما هو الحال في نموذج التنقل بنقطة الطريق (Waypoint)، والذي ينتج تداخلاً كبيرًا بين عقد الربط دون تحسين دقة التعريب. في هذه الورقة، نقوم بتحسين هذا النموذج من خلال التحكم في سرعة عقد الربط، في المخطط المقترح (EDAL)، تعد سرعة عقد الربط مهمة لحساب درجة التداخل بين عقد الربط وعدد العقد في الجوار، وبالتالي، يمكن لـ(EDAL)توزيع نقاط الربط بكفاءة لتحسين دقة التموضع وتوسيع مساحة التغطية في وقت واحد. نقيم أداء(EDAL)من خلال تجار بمحاكاة واسعة النطاق.

الكلمات المفتاحية: شبكات الاستشعار اللاسلكية المتنقلة، نموذج التنقل بنقطة الطريق.

1. Introduction

Mobile Wireless Sensor Networks (WSNs) consist of a large collection of small and low-cost devices [1]. These devices can communicate and collaborate with each other to collect and broadcast data. Mobile WSNs have been used in various applications, such as in disaster monitoring, tracking animals in wildlife sanctuaries, creates automatic mapping[2] and monitoring patients in hospital[3]. In tracking and monitoring applications[4-6], the location information of the collected data is crucial in estimating the precise location of the data origins[7].

In the literature, localization schemes of mobile WSNs can be classified into two categories, namely range-based and range-free[8]. The range-based category operates additional hardware, such as an array of antennas and acoustic devices to localize the sensor node [9],whereas the range-free scheme estimates the location of blind node (a node without location) via the network connectivity information without additional hardware.

In the range-free schemes, the anchor nodes broadcast its location information to aid in estimation of blind node location. However, the distribution of anchor nodes (a node with location information using GPS) over the operation area is highly affecting the network connectivity, coverage area and localization accuracy. Thus, it is important to design an efficient anchor node distribution method that able to expand anchor nodes throughout the coverage area which would lead to a better localization accuracy. The blind node requires at least three anchor nodes in the neighbor to estimate its location [10].

Most range-free localization schemes utilized the random waypoint mobility model to transmit the sensor node. Though the waypoint model has the advantage of being simple, it produces a large overlap between anchor nodes. The large overlap shows that the waypoint model is not efficient in distributing the anchor node since additional anchor nodes were used to cover an area even though they are not needed. This would consume more energy, requires more devices (e.g. GPS) and increase the overall cost of the whole implementation. An efficient node distribution for accurate localization should be able to maximize the coverage area by utilizing the available anchor node. This can be achieved by reducing the overlapping between the anchor nodes.

In this study, we develop a localization scheme to solve such problems by selecting the anchor node velocity as function of the overlap degree between anchor nodes and number of anchor nodes in the neighbor. The simulation results show that the proposed scheme can distribute anchor nodes efficiently, expand the anchor nodes coverage to 50% and improve the localization accuracy at the same time.

The rest of this manuscript is organized as follows: Section 2 presents the related work in localization scheme and mobility model. Section 3 explains the methodology of the EDAL scheme. The experimental protocol and its parameters are described and their results are presented in Section 4. Finally, Section 5 concludes the paper and outlines the future work.

2. Related Work

Compared to a static network, mobile WSNs have a higher coverage area with a limited number of sensor nodes. However, the mobility property of mobile sensors open a new challenge in estimating the location of blind node in WSNs. In this section, the related work is described in two sub-sections: localization scheme and mobility model.

2.1 Localization scheme

Localization schemes of mobile WSNs are categorized as range-based and range-free. The range-based scheme uses additional hardware to calculate the absolute distance between nodes. The deployment of additional hardware in WSNs is limited because of the restrictions in energy, size, cost and limited memory. Examples of hardware and their available methods are antenna which uses AoA[11], acoustic devices which measures the difference between light or sound signals via TDoA[12], and time synchronization between nodes in ToA. Another method in range-based scheme is received signal strength indicator (RSSI)that utilizes the relationship between signal strength and distance of the sensors. The localization accuracy of RSSI technology is affected by signal noise and weather conditions[13].

Range-free scheme estimates the location of blind nodes via network connectivity without additional hardware. In these schemes, three anchor nodes in the neighbor are required to estimate the blind node location in 2D space[10]. This estimation is based on the location information of the anchor nodes that broadcasted to the first and second hop neighbors in every time slot. Given the minimum dependency on anchor nodes, the range-free scheme is appropriate for indoor applications.

Location estimation of the mobile sensor node is a challenging task because the movement of mobile WSNs over time slot, in which affecting the localization accuracy. This challenge becomes more complicated for indoor localization applications since traditional solution such as GPS is highly affected by roofs, walls and other obstructions[14,15]. Additionally, the deployment of GPS in a sensor node is power-consuming and increases the costs and size of the sensor. Therefore, various localization schemes have been proposed to advance the location estimation of the mobile sensor in an indoor environment.

Mobile WSNs mainly use the SMC (Sequential Monte Carlo) technique to estimate the location of blind nodes in range-free schemes[16]. The SMC evaluates the posterior distribution function of the sample in the previous time slot to estimate the blind node location in current time. In each time slot, the normal node (node with location information in previous time slot) generates a new sample based on the sample from the previous time slot bounded by the maximum velocity (max-v). Anchor node constraints are then used to filter out the invalid samples. The processes are repeated until sufficient valid samples are generated. The average of weighted samples is later used for location estimation.

The Monte Carlo Localization (MCL) scheme[17] uses SMC technology to estimate the location of a blind node. Among the well-known techniques in WSNs localization which applies the SMC are MCL, MSL*, MCB and WMCL. In MCL, the location estimation of mobile sensor is simplified based on the following assumptions. First, the time is divided in an equal time slot, and second, the velocity of the sensor is limited to max-v. Moreover, the MCL estimates the location in three steps: initial, sample, and filter. The initial step involves the blind node generating samples randomly from the network bounded if it exists. This step is followed by the sample step, in which a new sample of the blind node is generated within a circle with a radius of max-v and is centered inside the area of previous time slot samples. In the filter step, anchor constraint is used to eliminate the weak samples and preserve the high weight samples. The anchor nodes constraints can be near or far and the near constraint is a region that is limited to radius R, whereas the far constraint is a region with a radius of R and 2R. The sample and filter steps should be repeated until sufficient valid samples are generated. The location estimation of the blind node is then calculated by averaging all valid samples.

In [18], MSL* was proposed to improve the localization accuracy of MCL. This technique uses the anchor and normal nodes location information in first and second hops. In each time slot, an anchor node and normal node broadcast their samples and sample weights to aid blind node location estimation. The sample weights of the anchor node are consistently high (one) and the normal node has a partial weight from zero to one. The weight of the normal node samples is calculated based on the distance between the samples of a normal node and the samples of another normal node in the neighbor. The use of normal nodes increases the localization accuracy substantially, but simultaneously increases the communication cost in WSNs. However, the communication cost is increased excessively in MSL* without improving the location accuracy. The communication cost of the MSL* is further improved in our previous research LCC [19] which emphasis on the selection of the closed normal nodes to the blind node based on the number of elements intersected between neighbors. This approach minimizes the communication cost while maintaining the localization accuracy as in MSL*. Nevertheless, the localization accuracy of MSL* decreases as the speed of the node increases. Thus, MSL* is more suitable for low-speed movement and static networks.

The MCB[20] scheme generates the sample from the bounded box method. The bounded box area is an intersection box between squares constructed by each anchor node over its center. This box minimizes the sample area and repetition in sample and filter steps. Thus, MCB scheme successfully improved the sampling efficiency but attained the same localization accuracy as in MCL. This is due to the fact that MCB used the same filtration strategy as in the MCL.

The sampling efficiency and localization accuracy of MCB are further improved in the Weighted Monte Carlo Localization scheme (WMCL) [21]. The WMCL improves the localization accuracy of MCB by using the location information of both normal and anchor nodes to generate and weight the candidate samples. The sampling efficiency is improved via location information of the blind node in the current time slot and its neighboring normal nodes location information in the previous time slot. The location information of the normal node comprises a sample set and maximum possible error of the estimated position in the x- and y- axes.

The WMCL is further improved in another method called the RMCB where it includes additional constraints of negative information to reduce the sample area, In this regard, RMCB uses both positive and negative anchor nodes constraints[22]. Contrarily, COMCL, PMCL, evaluates the distance and direction of the anchor node movement to decrease the scope of the sample area[23][39].

The Improved MCL (IMCL) scheme enhances the localization accuracy by introducing normal node location information [24]. This scheme consists of three steps: sampling, neighbor constraint, and refinement. In the sampling step, the blind node generates samples by exchanging messages with the anchor node as in the previous schemes. Then, the normal nodes will broadcast their location information, which contains position and length of eight sectors. Finally, the samples are filtered based on anchor node constraint and movement direction of normal nodes. Finding the length of eight sectors in this scheme require additional number of calculations and broadcasting the eight sectors length can increase the communication cost [41].

Typically, the blind node receives redundant messages from the normal nodes without further enhancing its localization accuracy. Therefore, distance from the normal nodes to the blind node and its maximum localization error has been proposed as a criterion to narrow the redundant messages[25]. Transmission of the location information is inhibited when the normal node exceeds the threshold value or has minimal localization error.

Orbit[26] improves the sampling efficiency by using a special graph theory known as star graph, which contains five edges in which the intersection of the edges present the bounded sample area. However, Orbit is more complex than the SMC scheme because Orbit increases the communication and computational costs. Moreover, finding five neighbors of a blind node is not consistently applicable all the time.

The EDAL scheme can improve the localization accuracy and maximize the anchor nodes coverage by controlling the anchor node velocity based on overlap degree between them. The velocity in EDAL is the function of the overlap degree between the anchor nodes whereas the previous schemes using random waypoint mobility model. Thus, the EDAL can maintain the number of anchor nodes in neighbors to improve accuracy and optimize the overlap degree between anchor nodes.

Table 1:

Comparison of SMC localization schemes

Studies	Mobility model	Accuracy	Communication Cost	Computation Cost	Dependent on anchors
MCL	Waypoint	Low	Low	High	Full
MCB	Waypoint	Low	Low	Medium	Full
MSL*	Waypoint	High	High	High	Partial
LCC	Waypoint	High	Medium	High	Partial
WMCL	Waypoint	Medium	High	Low	Partial
COMCL	Waypoint	High	High	Low	Partial
RMCB	Waypoint	High	Medium	Low	Partial
IMCL	Waypoint	High	Medium	Medium	Partial
Orbit	Waypoint	High	High	High	Partial
EDAL	EDAL	Medium	Low	Medium	Full

The localization accuracy in pervious schemes is improved by increasing the anchor node density and by utilizing normal node location information as presented in Table 1. However, increasing the anchor node density will increase the cost, size, power consumption and the connectivity of anchor node. Moreover, the location information of normal node is susceptible to present of error (its estimated location) and will maximize the communication cost in the network. Thus, the efficient distribution in EDAL can control the number of anchor nodes in the neighbors to increase the anchor node coverage and improve the localization accuracy.

2.2 Mobility Model

A mobility model is a design that models the changes ofsensor node location, velocity, direction and acceleration over time. This changes will rapidly modifies the topology in mobile WSNs[7] that in a period of time will affect network coverage and connectivity [16]. Generally, mobility models can be categorized as random, predictable, and controlled. The detailed comparisons, strengths, and challenges of the mobility models in the literature are discussed in[27-29].

An adequate investigation with at least one sensor node is essential in WSNs. This issue is mainly because of the movement of sensors can affect the coverage area in two ways. The optimistic way is to transfer the mobile sensor to more discovered areas, communicates with the isolated sensor, and extends network life[30]. However, nodes in static networks use the same routing path all the time to communicate with the sink, which consumes more power of sink neighbors and causes a split between the network and isolated sink node. The negative approach of the movement originates from the data lost in the handover process when the network disjoints into two parts. Moreover, sensors with high-speed movement can frequently disconnect and decrease network performance and stability.

The waypoint model permits the mobile sensor to move forward independently from its neighbors and its previous position. Hence, the movable sensor chooses its direction and velocity randomly without any correlation to its neighbors [8]. Such movement flexibility may not be the cases for certain applications such as speed of vehicles, disaster relief, battlefield, and other applications. The fact is that there are applications that movement can be controlled and a level of dependencyoccurs between the velocity of the nodes in the neighbors[31,32]. Another drawback of the waypoint model is the convergence of nodes close to the center of the simulation area[33], which decays the velocity of the respective nodes [34,35].

In the previous literature, the waypoint model was typically used in range-free localization schemes [16]. The main properties of waypoint model is the sensor node only retainedthe maximum and minimum velocities due to a small memory capacity, and this simplicity has led to its usage in most of the previous studies. Pause time is an important parameter in the waypoint model [36]. In the waypoint model, the pause time is set to zero, in which the sensor nodes move continuously without pausing time.

The movement of sensor node is highly dependent on the reference point or leader in the reference point group mobility model (RPGM). However, the election of the leader requires a long process, and the loss of the leader will affect the robustness and stability of the networks. Another issue in the RPGM is that each sensor node must request the leader for direction and velocity of movement in each time slot [8], which increase the communication cost in the networks and overhead for the leader. Therefore, RPGM is only suitable for specific application, such as museum visitors and conference members[37].

The inefficient distribution in the random waypoint and high dependency in RPGM mobility models maximizes the overlap between anchor nodes without improving localization accuracy. Based on this observation, we proposed localization scheme EDAL to control the movement of the anchor nodes based on the number of anchors in the neighbors and the degree of overlap between the anchor nodes.

3. Proposed scheme EDAL

Generally, mobile anchor nodes are used in the range-free schemes to aid location estimation of the blind node. Thus, the anchor nodes distribution is a critical issue in the localization process. An efficient distribution can increase the coverage of anchor nodes and network connectivity with minimum number of anchor nodes, while a weak distribution will leads to an excessive anchor nodes that will increase cost and energy consumption[33].

The overlap between sensor nodes is a critical issue in WSNs connectivity. The minimum overlap is important in maintaining connectivity and conserving the robustness of the networks. In contrast, a large overlap produces redundant messages and consumes extra energy without improving localization accuracy. Another critical issue in the localization process is a number of anchor nodes in the neighbors. A typical localization process in 2D space requires three anchor nodes in the neighbors to estimate a blind node location[10][40].

Based on these observations, we implement an efficient localization scheme to distribute the anchor nodes with an optimal overlap degree. The main challenge when the anchor node has the flexibility to move randomly is that the blind node can find more than three anchor nodes in the neighbor or two anchor nodes with large overlap degree as depicted in Fig. 1[10,38]. The EDAL scheme can effectively resolve this problem by correlating the velocity of the anchor nodes and the anchor node number in the neighbors with its overlap degree. The optimum value of velocity can maintain the robustness of the WSNs and increase the coverage areas.

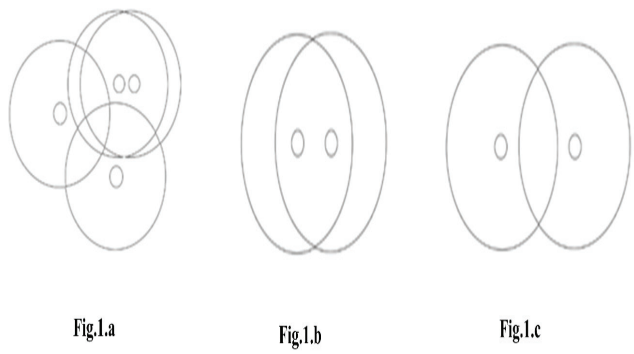

Fig.1.a

More than three anchor nodes in the neighbor

Fig.1.b

Two anchor nodes with extra overlap

Fig.1.c

Two anchor nodes with optimal overlap.

The velocity of the anchor node in EDAL scheme is set to maximum velocity (max-v) if a large overlap exist or more than three anchor nodes occur in the neighbors, whereas the minimum velocity (min-v) is chosen if small overlap occur, another velocity choose according to overlap degree (distance between anchor node) as presented in Algorithm 1. A small distance between two anchors nodes indicates a large overlap exist, whereas a large distance indicates a low overlap occur. Based on our simulation results, the distances between anchor nodes in the neighbors are divided into five periods and the velocity is associated with it, as in Algorithm 1. In this study, we used the minimum overlap of 1.73R as in[10].

Algorithm 1. A framework of EDAL localization algorithms.

Initial phase:

1. Find the number of anchor node in the neighbor (NA)

2. Calculate the distance between anchor nodes in the neighbors (The overlap degree (OD))

Velocity calculation phase:

If NA >= 3 or OD<=0.25R then velocity= max_v;

Else if OD> 0.25R and OD<= 0.50R then velocity= max_v * 0.75;

Else if OD> 0.50R and OD<= 0.75 R then velocity= max_v * 0. 50;

Else if OD> 0.75R and OD<= R then velocity= max_v* 0.25;

Else if OD> R and od< =1.75 R then velocity= min_v;

If OD < 1.75R then velocity= selected randomly;

Where R is the communication range, max_ is maximum velocity and min_v is minimum velocity.

4. Experimental setup and results

We tested the performance of EDAL scheme using various simulation parameters to verify its efficiency and compared it with previous localization schemes: MCL, MCB, MSL*, WMCL, and WMCLB schemes. The Java-based simulator code of MCL, MCB, and MSL* are received from the original authors, whereas WMCL, WMCLB and EDAL are implemented in the same simulator code provided by MCB authors[20].

4.1 Experimental setup

The normal nodes were set to move randomly based on the waypoint model and the anchor nodes were set to move based on the EDAL assumption. Anchor node density (Ad) is the number of anchor nodes in the first and second hops, whereas normal node density (Nd) is the number of anchor and normal nodes in the first hop.

In this experiment, the MCB scheme was selected to measure the performance of EDAL because it uses only anchor nodes observation in the localization process while other schemes use both anchor and normal nodes to improve localization accuracy. The use of normal nodes can increase communication costs and the overhead in the networks, moreover the location information of normal node is estimated location that impeded with the present of error. For these reasons, MCB was selected to measure the coverage of EDAL. Moreover, the MCB scheme also has an advantage over MCL in sample efficiency.

The EDAL scheme includes three important parameters: the degree of overlap between anchor nodes, the density of anchor nodes, and the velocity of the anchor node. The effect of each parameter is measured by several simulation tests and compared with MCB scheme over two different mobility models: waypoint and RPGM. The appropriate parameter values are selected and applied in the simulation.

The value of each parameter is calculated by executing 30 networks randomly. We simulated 1,000time units in each network, and then the time unit was averaged between 600 and 1,000 to assess each value. Each data point presented in this study was averaged by 30 independent experiment results. Other important parameters used during the simulation were the boundary of simulation area, which was set as 500 unit*500 unit, and the communication range (R) for anchor and normal nodes at 50 units. Time is a discrete time unit. In the initial setup, all sensors were distributed randomly over the simulation area. The pause time is set to zero, max-v is 0.2R, the number of samples is 50, Ad = 1and Nd =10, and the minimum overlap is 1.73R.

4.2 Experimental Results

The experimental results are described in two sub-sections. The first sub-section describes the coverage of the EDAL scheme in different overlap degrees and different anchor node densities. The second sub-section explains the measurement value of location accuracy in different velocity values, anchor nodes, normal nodes densities, and degrees of irregularity. Note: the MRPGM and M Waypoint means MCB scheme using RPGM and waypoint mobility model, respectively.

4.2.1 Coverage of EDAL scheme

The degree of overlap is measured by Euclidean distance, in which the small value of this similarity measure implies a large overlap between the anchor nodes and vice versa[10]. For example, a distance value lower than 0.1R indicates a substantial overlap, whereas a distance value near than1.73R indicates the optimal overlaps. The threshold value of the overlap degree is essential in ensuring the network stability. In this study, the threshold value of the overlap was set at1.73R as in [10].

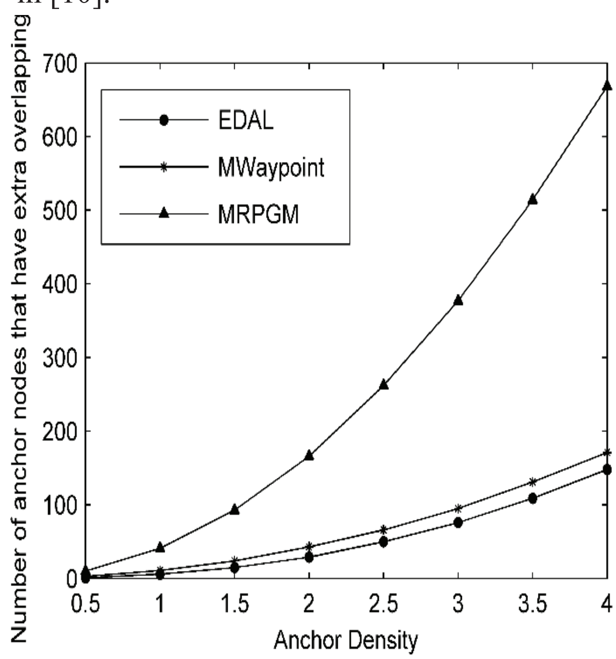

Fig. 2.

The relationship between anchor density and a number of anchor nodes with extra overlap.

The possibility of large overlap occurrence between the anchor nodes or finding more than three anchor nodes in the neighbors increase when the density of anchor nodes increases, as shown in Fig. 2. However, EDAL uses control velocity with the overlapping degree to optimize these overlaps and maximizes the coverage area with the same number of anchor nodes when compared with localization scheme using waypoint model. The inefficient distribution of anchor nodes in the waypoint and RPGM models increase the number of anchor nodes that have extra overlap. The group coherent almost requires minimum distance between neighbors that can produce huge overlap, as in RPGM. In the RPGM model, the increased of anchor node density can enormously increase the overlap degree because the localization parameters: velocity and direction of the anchor nodes are maintained based on the group leader decision.

Table 2:

Number of anchor nodes with extra overlap.

Mobility Model	Localization scheme				
	MCL	**MCB**	**MSL***	**WMCL**	**WMCLB**
RPGM	41	41	42	42	41
Waypoint	10	11	10	10	10
EDAL	6	6	6	5	6

Different localization schemes (MCL, MCB, MSL*, WMCL, WMCLB) are used to examine the efficiency of the EDAL. The performances of these schemes are listed in Table 2 and 3. Table 2 presents the number of anchor node with extra overlap degree in different localization scheme based on RPGM, waypoint mobility models and EDAL assumption and Table 3 presents the localization accuracy. The number of anchor node with large overlap is highly affected by mobility model type and slightly affected by variation of the localization scheme. These results showed the importance of controlling anchor node velocity in its distribution. EDAL can optimize the number of anchor node with extra overlap degree in each localization scheme with 50% while maximizing the coverage area as compared to the waypoint model. The RPGM model has the highest number of extra overlap degree in all schemes.

Table 3:

Localization accuracy in different schemes.

Mobility Model	Localization scheme				
	MCL	**MCB**	**MSL***	**WMCL**	**WMCLB**
RPGM	0.55	0.54	0.42	0.48	0.39
Waypoint	0.56	0.56	0.31	0.38	0.40
EDAL	0.51	0.51	0.28	0.34	0.35

Similarly, the results in Table 3 showed that the localization accuracy can be improved by controlling the anchor nodes velocity. The performance of the EDAL attained the highest localization accuracy among the tested schemes.

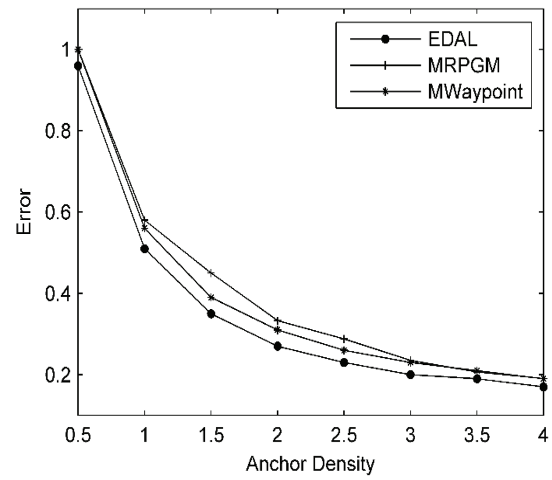

Fig. 3.

Anchor node density and localization error.

The increase of anchor node density can improve the localization accuracy in all schemes, as shown in the figure 3. EDAL is capable of improving the localization accuracy faster in all cases with optimal number of anchor nodes. In the MRPGM, the localization accuracy is less improved because the blind node requires to ask the group leader for location information per each time slot. The localization accuracy in the Waypoint also improved less when compared with EDAL.

From this results, we can show the important of anchor node distribution and how much the random movement can produce large overlap without improving the localization accuracy.

4.2.2 Localization Accuracy

Accuracy is the most important parameter in the localization process. For this, the accuracy of EDAL scheme measured based on the effective parameters: anchor node density, normal node density, velocity, and degree of irregularity.

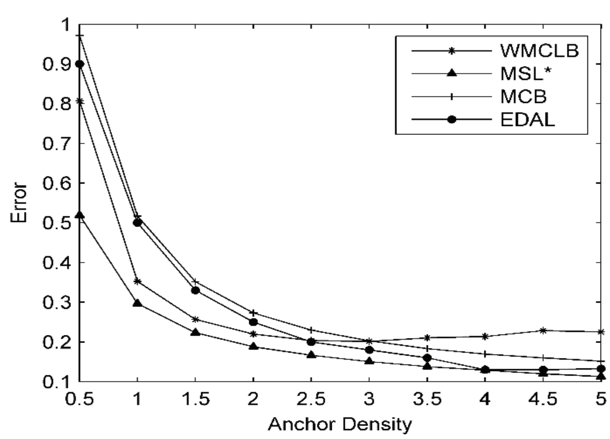

Fig .4.

Accuracy and anchor node density.

Anchor node density: In Fig. 4, the localization accuracy of EDAL and MCB rapidly improved with the increasing of anchor nodes density because they draw observations primarily from the anchor nodes. Other schemes that draw observations from the anchor and normal nodes, such as MSL* and WMCLB, are less affected by the increment of anchor node density. Nevertheless, the increment of anchor node density can be reflected negatively in the power consumption and dependency on hardware such as GPS. EDAL has a capability to improve the localization accuracy comparable with other schemes in the case of large anchor nodes density, results in Fig.4 show that at the anchor node density equal to 4, EDAL can improve the localization accuracy more than other schemes even it use normal node location information like MSL* and WMCLB.

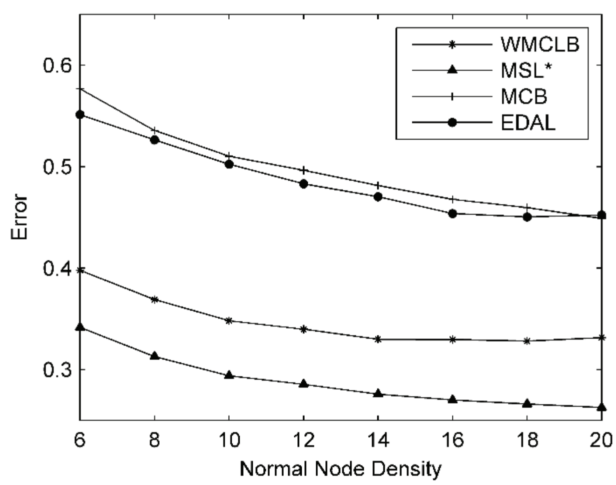

Fig. 5.

Accuracy and normal node density.

Normal node density: Localization accuracy can be improved with the increment of normal node density, as shown in Fig.5.The observation on EDAL and MCB only shows small percentage of improvement when the normal nodes increases. This is because both methods broadcast the location of anchor nodes to the first and second hop sensors in the neighbor. However, MSL* and WMCLB shows the opposite reaction because they draw observations from both anchor and normal nodes in the neighbors. MSL* is more effective than WMCLB because it uses all normal nodes samples in the first and second hops to draw observations with high communication costs. WMCLB uses bounded box over normal nodes to improve sampling efficiency and filter out the invalid samples. Thus, it is more sensitive to changes in normal node density.

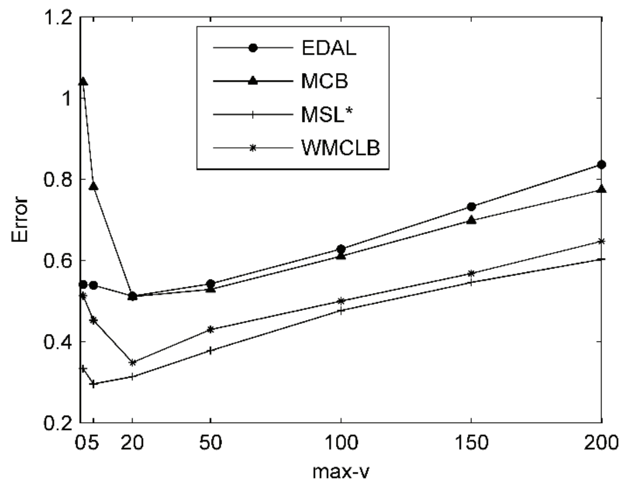

Fig. 6.

Accuracy and velocity of sensor nodes.

The velocity of nodes: Fig.6 shows that the movement of sensor nodes can improve the localization accuracy by receiving new anchor nodes and finding more observations. Movement with limited velocity can further improve the localization accuracy because the blind node can use some previous location information in the last time slot. A thigh-velocity, sensor can move to a farther distance from the previous location, thus the location information in previous time slot cannot improve the localization accuracy. Fig.6 shows that all schemes have high accuracy at velocity equal to 20.This value is used throughout this study as default value for velocity.

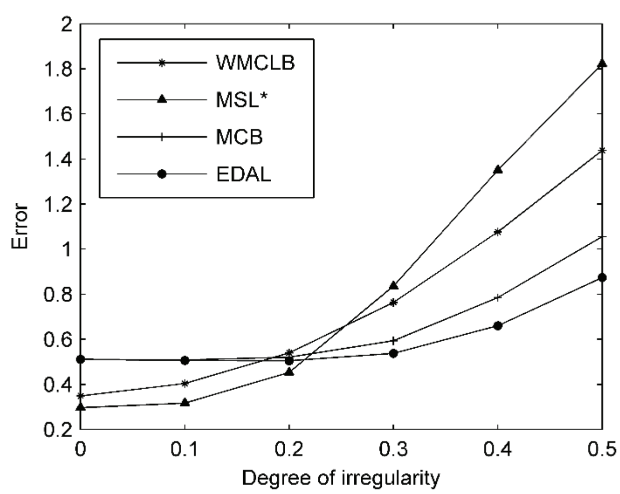

Fig. 7.

Accuracy and degree of irregularity.

The degree of Irregularity (DOI): Fig.7 shows the effects of DOI on localization accuracy wherein the increase of DOI minimized the localization accuracy in all schemes. However, in real-world applications, the signals can be interrupted by noise and affected by antenna direction and natural phenomena such as humidity and walls. In some cases, the distance between two sensor nodes is nearly half the radio range; in this case, they cannot communicate because they share a large variation of radio range. A full circle in EDAL was used during the experiments to present the communication range of the sensor nodes.

5. Conclusions and future work

The random velocity used in previous schemes based on waypoint mobility model has a large overlap between the anchor nodes that consumed more power and reduced the coverage area without improving the location accuracy. However, the EDAL can distribute the anchor nodes efficiently using the adaptive velocity with overlapping degree between the anchor nodes in the neighbors. Nevertheless, the patterns of movement remains an open research area in mobile WSNs. In future, we intend to extract the features of the mobile node movement from the real experiment and implement EDAL in real experiments to measure its efficiency.

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In vitro and In vivo Evaluation of a Plant Origin Acaricide and In vitro Evaluation of Plant Extracts Against Two-Spotted Spider Mite, Tetranychus urticae Koch

التقييم المخبري والحقلي لمبيد أكاروسي من أصل نباتي والتقييم المخبري للمستخلصات النباتية على الأكاروس العنكبوتي ذو البقعتين، Tetranychus urticae Koch

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Abstract

This study was performed at Sweida Research Center/GCSAR/ in Syria during 2016. The effect of garlic and soft wheat crude extracts as well as the effect of matrine (plant-based acaricide), jolly and sanmite (chemical-based acaricides) were tested under in vitro conditions on two-spotted spider mite, Tetranychus urticae Koch (TSSM). In addition, acaricides used were evaluated under in vivo conditions. Survival % of TSSM was calculated, neglog transformed and subjected to ANOVA analysis using Tukey HSD test. In vitro bioassay results revealed a significant effect of garlic and wheat extracts as well as matrine, jolly and sanmite. After 72 hours, no difference was observed between plant extracts, and among tested acaricides. In vivo bioassay results also showed a significant effect of acaricides used where jolly was the best and matrine and sanmite were comparable. These findings support the idea of using plant-based acaricides (including lectin-based acacicides) as an alternative strategy of using chemical-based acaricides. Taking into account the advantages of in vitro bioassays and based on the results of this study, we suggest predicting in vivo response from in vitro results although this issue needs to be tested first for the crude plant extracts to evaluate their stability under in vivo conditions.

Keywords: Spider Mite, Plant Extract, Matrine, Survival %, Lectin.

ملخص:

نُفذت هذه الدراسة في مركز بحوث السويداء/ الهيئة العامة للبحوث العلمية الزراعية، سورية خلال العام 2016. وجرى اختبار تأثير المستخلص الخام لكل من القمح الطري والثوم، بالإضافة إلى الماترين (مبيد أكاروسي من أصل نباتي) والجولي والسانمايت (مبيدات أكاروسية من أصل كيميائي) على الأكاروس العنكبوتي ذي البقعتين Tetranychus urticae Koch تحت الشروط المخبرية. بالإضافة لذلك، جرى تقييم المبيدات الأكاروسية المختبرة تحت الشروط الحقلية. حُسبت % النجاة للأكاروس العنكبوتي ذي البقعتين، ثم حُولت البيانات وعُرِّضت لتحليل التباين باستخدام اختبار Tukey HSD. بينت نتائج الاختبارات الحيوية المخبرية وجود تأثير معنوي لمستخلصي الثوم والقمح بالإضافة إلى الماترين والجوليوالسانمايت. لم تُلاحظ وجود فروقات فيما بين المستخلصات النباتية المستخدمة، وفيما بين المبيدات الأكاروسية المستخدمة بعد 72 ساعة. كما بينت نتائج الاختبارات الحقلية وجود التأثير المعنوي للمبيدات المستخدمة حيث كان المبيد جولي الأفضل، بينما كان تأثير الماترين والسانمايت متشابها. تدعم هذه النتائج فكرة استخدام المبيدات ذات الأصل النباتي (بما فيها المبيدات ذات الأصل اللاكتيني) كإستراتيجية بديلة عن استخدام المبيدات ذات الأصل الكيميائي. آخذين بالاعتبار إيجابيات الاختبارات المخبرية ونتائج هذه الدراسة، نقترح إمكانية التنبؤ عن الاستجابة في التجارب الحقلية انطلاقا من نتائج التجارب المخبرية على الرغم أن هذا التنبؤ يحتاج لاختبار فيما يخص تأثير المستخلصات النباتية الخام لتقييم ثباتها تحت الشروط الحقلية.

الكلمات المفتاحية: الأكاروس العنكبوتي، المستخلص النباتي، ماترين، % النجاة، اللاكتين.

Introduction

Secondary pest outbreak is caused by using broad-spectrum insecticides that disrupt natural pest control due to the toxicity of these insecticides on non-target biological enemies. This is the case for two-spotted spider mite (TSSM), Tetranychus urticae (Koch). TSSM has a wide range of hosts (more than 1200 species), 150 of them are economically significant (Zhang, 2003).The population of these mites can reach high density quickly, and subsequently reduces the quality and quantity of crops especially after sever infestations.

Mites feed on the leaves by sucking the plant sap. As a result, the photosynthetic efficiency decreases due to the loss of chloroplasts and this eventually will lead to leaf death (Tanigoshi et al. 2004).

As conventional insecticides are used in several agro-ecosystems (Sarwar, 2015) and because TSSM has turned to be a key pest at present, agriculture is facing a serious problem. Spider mites have developed resistance to pesticides rapidly where resistance to over 80 pesticides covering most major chemical groups has been reported (APRD, 2007).It is worth mentioning that TSSM populations (and other mites) have the highest occurrence of pesticide resistance among arthropods in agricultural habitats (Van Leeuwen et al., 2015). In addition, some of insects' biological enemies are sensitive to pesticides (Zanuncio et al., 1998), which will decrease their efficiency for biological control (Biondi et al., 2015). These concerns have directed researchers' attention to search for alternative control methods such as natural pesticides derived from plants (Isman, 2006). Plant extracts are one of the non-chemical control options that have recently received more attention. There are several reports on botanical acaricides proved to be effective against TSSM like neem (Martinez-Villar et al., 2005) and garlic (Boyd and Alverson, 2000).

Biological control and plant-based pesticides are important for developing an Integrated Pest Management Program (Jansen, 2013). Hence, using plant-based pesticides could be an effective strategy to control pests and reduce negative effects of synthetic pesticides.

Therefore, this study focuses on the effect of three acaricides (one of them is derived from plant origin) on TSSM under laboratory and field conditions as well as the effect of two plant extracts under laboratory conditions. In addition, this study addresses the possibility of predicting the in vivo response starting from the in vitro results.

Methods and materials

This study was performed at Sweida Research Center/ GCSAR/ Syria during 2016. The in vivo bioassay was achieved in a homogenized apple field with the following characteristics: soil: loamy clay, apple cultivar: Starkrimson (the age is unified: 30 years) grifted on the rootstock MM 109, altitude: 1550 meter above sea level, average of annual precipitation: 550 millimeter, the weather is hot, dry in summer, and cold in winter.

Preparation of tested acaricides and plant extracts

The toxicity of certain acaricides (matrine is a plant-based acaricide whereas jolly and sanmite are chemical-based acaricides), along with water as a control was tested using the manufacturer recommended concentrations (Table 1) under in vitro and in vivo conditions. In addition, the effect of garlic and soft wheat crude extracts was also tested under in vitro conditions where extraction buffer (0.2 M Nacl) was used as a control. Ten grams from each of the garlic gloves and wheat grains (Bohuth 8: soft wheat) were homogenized in 80 ml of extraction buffer following the ratio 1 to 8 (w/v) (Hou et al., 2010). The homogenates were left at room temperature for 24 hours (H) with stirring several times. Afterwards, the homogenates were filtered using a filter paper, and the resultant solutions were kept at 4° C until use.

Table 1.

Acaricides used and their application rate

Trade name	Effective ingredient	Application rate
Matrine	Matrine 0.5%	100 cm3/ 100 L water
Jolly	Fenbutatin oxide 50%	100 cm3/ 100 L water
Sanmite	Pyridaben 20%	100 g/ 100 L water

Preparation of TSSM

TSSMs were collected from several apple orchards at Sweida Research Center/GCSAR, where no pesticides were used. The mites were brought into a greenhouse and were released on potted kidney bean plants (Phaseolus vulgaris L).

In vitro bioassay

The in vitro bioassay was performed following the method of Sikha et al (2011) with some minor modifications. Complete randomized design with six replications was used for this assay. Apple leaf disks (2 cm diameter) were immersed in each of the different solutions used, and immediately air-dried for ½ H. After that, leaf disks were put in petri plates (9 cm diameter) on wet cotton to keep them turgescent. TSSM adults were collected from the culture and moved to the leaf disks/ 10 mites on each leaf disk/ 3 leaf disks per plate/ 6 plates per treatment at room temperature. Mites regularly observed after 24, 48 and 72H by stereomicroscope. Mites were considered dead when not showing any movement.

In vivo bioassay

Randomized complete block design with three replications was used for the in vivo bioassay. Applied treatments were the three tested acaricides and water as a control. TSSM population (adults and nymphs) was registered on 3 replicates/ 3 trees per replicate/10 leaves per tree (from different parts of the canopy) for each treatment before the spray in addition to 3, 7, 10, 15 and 21 days after spraying. The leaves were passed through a mite-brushing machine and afterwards placed onto a circular glass plate that is coated with a thin layer of glycerol to catch the mites (Henderson and Mc Burnie, 1943).

Data collection and analysis

For both bioassays, the number of living adults (moving stages: adults and nymphs for the in vivo bioassay) was converted into survival % which subsequently neglog transformed (Whittaker et al., 2005) and finally subjected to analysis of variance (ANOVA).Neglog transformation is normally used to reduce the heterogeneity of the data especially when performing bioassays and using percentage data. This method has been used before (Belay et al., 2018). Survival %was expressed as means ± standard deviations. The means were compared using Tukey HSD test at 0.01 probability level for the in vitro bioassay and at 0.05 probability level for thein vivo bioassay by using the SPSS program version 19.

Neglog = (sign X) * Ln (|X| + 1). X is survival %.

Results and discussion

Effect of acaricide and plant extract treatments under in vitro conditions

The effect of several acaricides including matrine (a natural-based acaricide extracted from wild medicinal plant, Sophora flavescens Ait), jolly and sanmite (chemical-based acaricides) was evaluated under in vitro conditions at different time points. ANOVA results showed a significant effect of acaricide application on the survival % of TSSM as compared to the control (Fig 1, Table 2). No difference was observed after 24 H among tested acaricides whereas only matrine reduced the survival % significantly compared to the control after 48 H. All tested acaricides showed significant differences compared to the control after 72 H but no difference was registered among them (Fig 1).

The survival % of the control treatment (only water) was registered 91%, 88%, 78% after 24H, 48H and 72H, respectively (Fig 1).

Table 2.

Mean square of survival %(transformed data) for tested acaricides under in vitro conditions after 24H, 48H and 72H

Source of variance	d.F	24H	48H	72H
Treatment	3	0.028	0.786**	1.176**
Error	20	0.01	0.01	0.073

**: indicates significant differences at P-value < 0.01

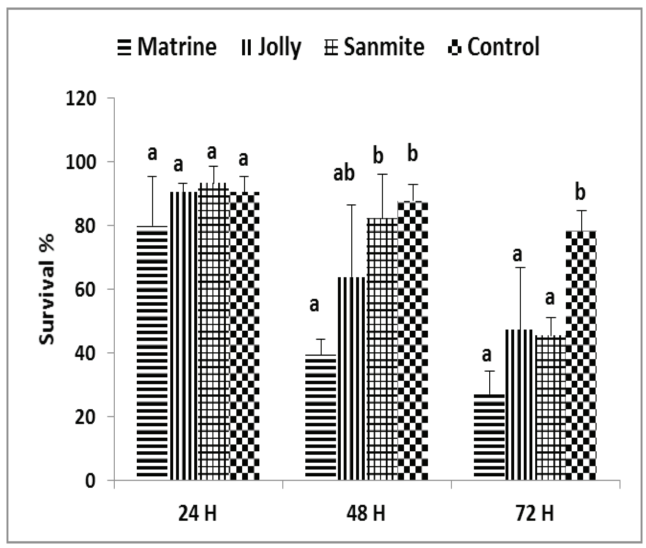

Fig. 1.

Survival % of TSSM adults after immersing leaf disks in tested acaricides: matrine, jolly, sanmite and water as a control. The survival % after 24hours (H), 48 H and 72 H is shown. Bars represent means ± standard deviation based on 6 replicates (plates)/three leaf disks per plate/10 adults per leaf disk. Within each group (24H, 48H or 72H) different letters indicate significant differences at P-value < 0.01 (Tukey test).

Crude extract effect for garlic gloves and soft wheat grains was also tested under in vitro conditions. Both extracts had significant effect compared to the control especially after 72H although no difference was observed between the two tested extracts (Fig 2, Table 3). After 24H, the effect of tested extract was comparable to the control, but only garlic extract shows significant effect on TSSM survival % after 48H proving its rapid efficacy compared to wheat extract (Fig 2).

The survival % of the control treatment (0.2 M Nacl) was registered 94%, 78%, 56% after 24H, 48H and 72H, respectively (Fig 2). This reduction can be explained by the effect of Nacl, which is apparently greater than the effect of only water especially after 72H (56% for the salt treatment and 78% for water treatment). The reduction of survival % in both controls might also be due to the insufficient food (only 2 cm diameter leaf disks were used). In addition, the in vitro bioassay was performed at room temperature, which is not optimum for TSSM. Under field conditions, the average maximum temperature in June, July and the first half of August (2016) was 30°±2.4° C (Climate Measuring Station/ Sweida Research Center).

The effectiveness of garlic and wheat crude extracts is most probably due to the effect of lectins, even though the effect of other components cannot be excluded. The activity of lectins, which are carbohydrate-binding proteins, against insects was proven and received a lot ofattention (Vandenborre et al., 2011; Bharathi, 2017).Constitutively expressed lectins are often concentrated in seeds or vegetative storage tissues, and they probably act as storage proteins (Van Damme et al., 1998). However, in case of pest attack they play a role as defense-related proteins against pathogens and insects (Roy et al., 2014). Garlic gloves and wheat grains contain lectins called Allium sativum agglutinin, and wheat germ agglutinin, respectively. Their insecticidal activity has been reported in transgenic plants (Sadeghi et al., 2007), and by using the lectin in artificial diets (Harper et al., 1998), or by using the purified lectin in bioassays (Roy et al., 2008).

Table 3.

Mean square of survival % (transformed data) for tested plant extracts under in vitro conditions after 24H, 48H and 72H

Source of variance	D.F	24H	48H	72H
Treatment	2	0.014	0.191**	0.971**
Error	15	0.005	0.026	0.077

**: indicates significant differences at P-value < 0.01

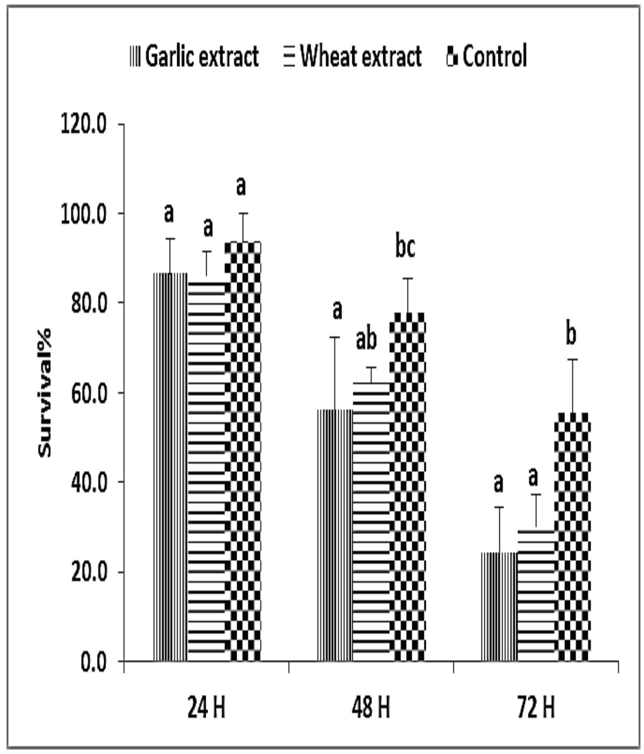

Fig. 2.

Survival % of TSSM after immersing leaf disks in tested plant crude extracts: garlic extract, wheat extract and 0.2M Nacl as a control. The survival % after 24H, 48H and 72H is shown. Bars represent means ± standard deviation based on six replicates(plates)/ three leaf disks per plate/ 10 adults per leaf disk. Within each group (24H, 48H or 72H) different letters indicate significant differences at P-value < 0.01 (Tukey test).

Effect of acaricide treatments under in vivo conditions

The acaricide treatments were effective in controlling TSSM population under in vitro conditions. Therefore, a bioassay was conducted to evaluate their effect under field conditions, and to compare the effect of the plant origin acaricide with the chemical-based acaricides. The results revealed a significant reduction in survival % of TSSM moving stages at 3 days (D), 7D and 10D after spraying for all tested acaricides(Fig 3, Table 4). At the three mentioned time points, Jolly was the most effective acaricide against moving stages of TSSM (survival %: 5.1%, 2.6%, 0.4% at 3D, 7D, 10D respectively, P-value < 0.05). It is not surprising that jolly was more effective than matrine under field conditions (they were comparable after 72H under in vitro conditions, Fig 1) because only adults were observed for thein vitro bioassay whereas moving stages (adults and nymphs) were registered for thein vivo bioassay. Additionally, both bioassays were assessed at different durations (3 days for the in vitro bioassay and 21 days for the in vivo bioassay).

In general, using matrine is safe to beneficial arthropods and to the environment (Wang et al., 2012) because its plant origin. In addition, registering no significant difference between matrine and sanmite (Fig 3) supports the idea of using matrine instead of synthetic pesticides. Furthermore, the effective ingredient of matrine is very low 0.5% compared to 50% of jolly and 20% of sanmite (Table 1). This means that there is a possibility to increase the effective ingredient of matrine to be more efficient although this issue has to be proven first. Matrine is a quino lizidine alkaloid extracted from Sophora flavescens (Liu et al., 2008). In accordance with our results, matrine has been reported to be effective against mites (Niu et al., 2014).Taking into account the high toxicity of chemical origin pesticides towards the environment, biological enemies, animals (Mahmood et al., 2016) and human beings (Nicolopoulou-Stamati et al., 2016), there is a continual need to use safer alternatives particularly plant origin pesticides.

Table 4.

Mean square of survival % (transformed data) for tested acaricides under in vivo conditions 3, 7 and 10 days after spraying

Source of variance	D.F	3D	7D	10D
Treatment	3	4.476*	3.628*	3.760*
Block	2	0.018	0.068	0.017
Error	6	0.064	0.022	0.060

*: indicates significant differences at P-value < 0.05

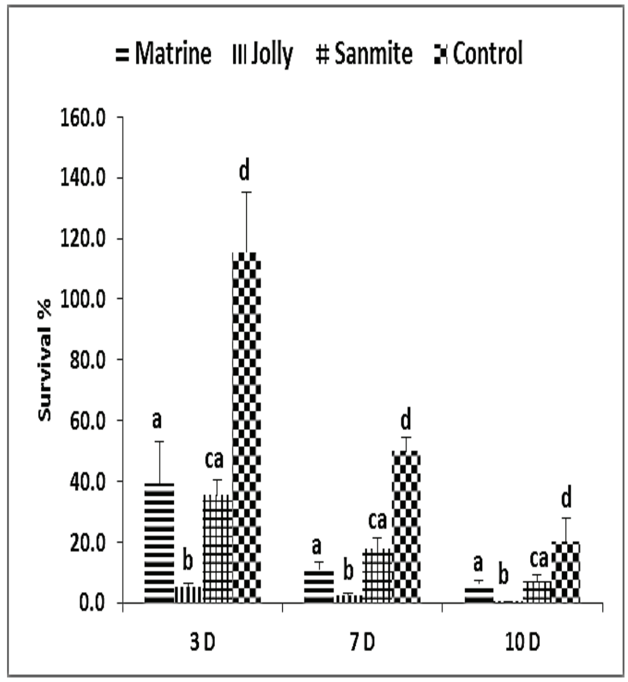

Fig. 3.

Survival % of TSSM for in vivo bioassay after spraying with tested acaricides: matrine, jolly, sanmite and water as a control. The survival % after 3 days (D), 7D and 10D is shown. The average of moving stages number before spraying were 476, 513, 967 and 383 for matrine, jolly, sanmite and control treatments, respectively. Bars represent means ± standard deviation based on 3 replicates/ 3 trees per replicate/ 10 leaves per tree. Within each group (3D, 7D or 10D) different letters indicate significant differences at P-value < 0.05 (Tukey test).

Even though observation was registered, 15D and 21D after spraying, obtained data were not subjected to ANOVA because the mean number of TSSM in the control treatment was reduced naturally (Fig 4). This reduction in TSSM number is probably due to the high maximum temperature registered during the second half of the in vivo bioassay (36.2° ± 0.9° C), whereas it was 30° ± 1.9° C during the first half of the bioassay (Climate Measuring Station/ Sweida Research Center). The field experiment was deliberately started when the number of TSSM reached the highest values at the late season. This may also explain the reduction of TSSM number (control treatment) because TSSMs started entering the diapause period at the late season.

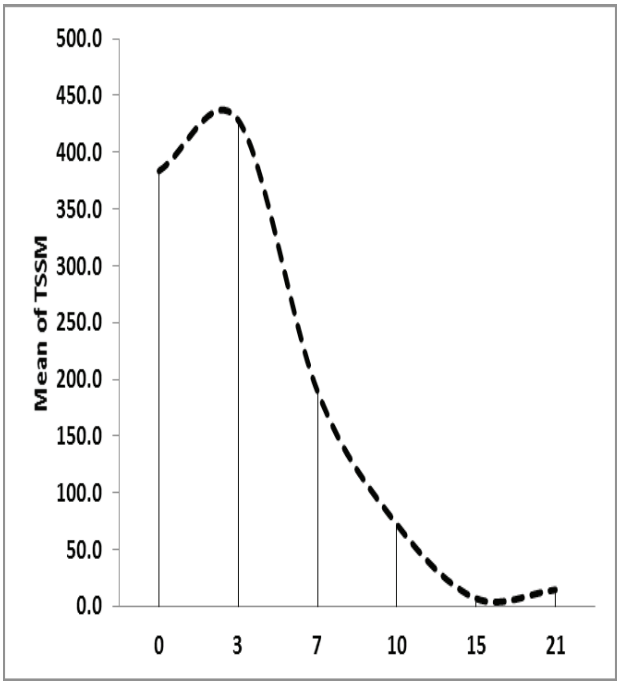

Fig. 4.

Mean of TSSM number (moving stages) in the control based on 3 replicates/ 3 trees per replicate/ 10 leaves per tree for the in vivo bioassay. Horizontal axis represents the time points (in days) of observations.

Prediction of in vivo response from in vitro bioassay results

In vitro bioassays have the potential to yield very important data but extrapolation to in vivo responses remains a major challenge. In vitro bioassays are easy to perform, rather cheap and not time and labor consuming. In addition, large numbers of treatments can be performed in a small place. On the contrary, in vivo bioassays are expensive, difficult to conduct, and time and labor consuming. This encourages researchers to test their treatments under in vitro conditions first especially that in vitro bioassays can screen their treatments before testing them in the field. It has been reported that the results of in vitroare still true for in vivo (Pokle and Shukla, 2015; Reddy et al., 2014).

Back to the issue raised by this study: can in vitro results be generalized to field conditions? Based on the results of this study and on some reports (Mamun et al., 2014), the answer is yes although this issue is still a prediction. At least, treatments can be screened and selected under in vitro conditions before being tested under in vivo conditions.

In the present study, plant extracts proved to be efficient under in vitro conditions but before this result can be generalized to field conditions their stability under field conditions has to be proven. This stimulates further researches to test this issue especially that plant extracts (rich in lectins like garlic and wheat) will pave the way of using acaricides derived from these extracts.

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Using Linear Mathematical Programming Model to Reduce Feed Cost of Broiler Farms

استخدام نموذج البرمجة الخطية الرياضية لتقليل تكلفة العلف في مزارع الفروج

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Abstract:

This research aims at shedding light on the effectiveness of using linear mathematical programming models in the production management of Broiler farms, and proposing the optimal low-cost Broiler feed mix within the constraints of the available feed resources. The research also aims at studying the effect of the low cost of the mixt on the proposed financial evaluation indicators. Primary data were collected through a random sample of broiler chicken farmers to obtain data related to the production costs, revenues and technical operations during the production season of 2018 in the governorate of Swaida, Syria. The results showed that the total cost of one ton of the proposed starting batch, obtained by using the linear programming model, was 196,953.93 SYP/ton, meaning the cost decreased by 16.2%. While the total cost of one ton of the final mix proposed for the linear programming model amounted to 191324.8 SYP/ton, the cost decreased by 16.8%. Through analyzing the impact of feed costs' decline by 16% on the financial assessment indicators of the sample, it can be noted that the variable expenses decreased to 7,205,866 SYP/farm in the summer production cycle and to 8,150,358.4 SYP/farm in the winter production cycle. The value of the net income index and the gross margin increased to 9,214,777.9 SYP/farm and 1,206,278.04 SYP/farm respectively for the mix obtained by the programming model. The revenue to costs ratio increased to 1.123%, and the operating ratio decreased to 0.89%. Moreover, it was noted that the profitability of the invested SYP increased to 12.3%, and the time of the variable assets turnover decreased to 312.66 days.

Keywords: Linear Mathematical Programming, Optimal Diet, Broiler Chicken, Economic Indicators, Production Costs.

ملخص:

يهدف البحث إلى إلقاء الضوء على فعالية استخدام نماذج البرمجة الرياضية الخطية في إدارة الإنتاج لمداجن الفروج، واقتراح أفضل تركيبة علفية للفروج تخفض التكاليف، ضمن قيود الموارد العلفية المتاحة، ودراسة تأثير انخفاض تكلفة الخلطة المقترحة في مؤشرات التقييم المالي المدروسة، وقد جرى الاعتماد على بيانات أولية، من خلال عينة عشوائية من مربي فروج اللحم للحصول على بيانات متعلقة بتكاليف الإنتاج والإيرادات والعمليات الفنية للموسم الإنتاجي 2018 في محافظة السويداء السورية، وبينت النتائج أن: إجمالي تكلفة الطن من الخلطة البادئة المقترحة بتطبيق نموذج البرمجة الخطيّة بلغ 196953.93 ل.س للطن، أي انخفضت التكلفة بنسبة %16.2. في حين أن إجمالي تكلفة الطن من الخلطة الناهية المقترحة لنموذج البرمجة الخطيّة بلغ 191324.8 ل.س للطن، أي انخفضت بنسبة %16.8، وبدراسة أثر انخفاض تكلفة العلف %16 في مؤشرات التقييم المالي المحسوبة للعينة، ويلاحظ أن قيمة التكاليف المتغيرة انخفضت إلى 7205866 ل.س للمدجنة في الدورة الصيفية، وإلى 8150358.4 ل.س للمدجنة في الدورة الشتوية. وقيمة كل من مؤشر صافي الدخل والهامش الإجمالي ازدادت إلى 921477.9 و 1206278.04 ل.س/للمدجنة للخلطة المستخرجة بنموذج البرمجة، وارتفاع قيمة نسبة الإيرادات للتكاليف إلى %1.123، ونسبة التشغيل التي انخفضت إلى %0.89، في حين أن أربحية الليرة المستثمرة ارتفعت إلى %12.3، وزمن دوران الأصول المتغيرة قد انخفض إلى 312.66 يوم.

الكلمات المفتاحية: البرمجة الخطية الرياضية، عليقة مثلى، الفروج، مؤشرات اقتصادية، تكاليف إنتاج.

Introduction

Broiler farming is considered an economic advantage, placing the poultry sector within the top industries as it increases the amount of protein in the person's diet, contributes in (gross national income) GNI, does not require massive space for its production, has high manufacturing efficacy, and has quick turnover of the invested capital and short lifespan (45-55 days) (Al-Jojo, 2006). It is important for countries like Syria, which is characterized by increased population growth, limited natural resources and a challenging climate, to optimize the use of the available resources and foster the concept of sustainability to have constant economic growth. This requires the implementation of policies that are based on resources productivity assessment in the sector of agriculture, in order to reach the maximum level of resources' economic revenues, while maintaining the resources' productivity. Thus, production policies in Syria should seek to establish the highest possible level of resources' productivity in the most efficient and economic manner (National Agricultural Policy Center, 2002). Farm planning seeks to distribute economic resources in a way that guarantees the optimal use of these resources in accordance with the present capabilities and conditions. Thus, linear programming is considered one of the most important planning methods to find the optimal approach for utilizing resources for a project (Al-Ashari, 2011).

Research Importance and Justification

Broiler farming is considered an agricultural activity that is influenced by various factors and uncontrolled external variables such as, climate change, environmental fluctuations, diseases, price fluctuations of production inputs and extent of openness to global markets. Consequently, chicken farmers have multiple production targets that are subject to a number of constraints related to the availability of economic resources. Thus, the importance of research stems from the necessity to implement effective scientific methods that help reduce the cost of feed of broiler farms and achieve possible maximum profit.

Purpose of the Research

The research aims at shedding light on the efficiency of utilizing linear mathematical programming for reducing the cost of feed of broiler farms. ***This purpose is achieved through:***

1. Analyzing the most important financial evaluation indicators for broiler farming projects in Swaida governorate.
2. Proposing the optimal feed mix that decreases costs, taking into consideration the constraints of the available feed resources.
3. Analyzing the impact of the proposed feed mix on financial evaluation indicators.

Previous Studies

A number of studies tackled the topic of financial evaluation of poultry farming projects.

Balao, Abdul Hussein, and Abed (2018) revealed that producers in al-Muthanna governorate in Iraq were incompetent in using production inputs, especially pharmaceutical drugs. However, it was noted that their net cash flow, net farm income and farm work revenues amounted to 30461.82 IQD; 2877825 IQD; 28023.04 IQD respectively. Return of capital was found to be 1.057 and payback period was found to be 0.88 year. These are considered good indicators for the projects.

Darwish and Younes (2016) explored how the crisis in Syria affected broiler farming and production through comparing prices and costs before and after the crisis. Results showed that productive efficiency of broiler farming in Latakia was 1.85 in 2010 and 1.20 in 2014. Economic efficiency was found to be 1.72 in 2010 and 1.09 in 2014. Payback period was found to be 1.3 year in 2010 and 9.8 years in 2014.

Jado (2013) revealed that the most important production inputs that impact Broiler production in Egypt are the number of chicks, amount of feed, number of hours of human labor, and number of dead chicks. These variables were proved to be significant. The average net revenues for the sample was found to be 2,178.43 EGP/ton. Al-Aboudi's (2014) study used the linear programming method to identify the optimal feed. The price of one ton of the feed obtained by the mathematical programming was 116,861 IQD less than the low-quality standard feed sold at the local market.

Nath and Ashok (2014), showed the optimal solution of the linear programming model provides feed mix lower in costs than the current feed. The researchers developed a feed mix composed of 22.98 kg of rice bran, 3.96 kg of wheat bran, 15.32 kg of fish meat, and 57.72 kg of sesame seeds. All of these ingredients constituted 100 kg of feed which contained the minimum requirements of macronutrients. The 100 kg cost was estimated to be 1,426.57 INR.

Al-Masad, al-Tahat, and al-Sharafat (2011), using linear programming model, revealed different feed mixes used in the diet of egg laying chicken in Jordan in addition to the present market prices and ingredients. It was noted that the cost of one portion of feed in all stages was 25-45 JD less per ton than the standard feed mix sold at the market.

Al-Deseit (2009), showed that the optimal feed mix, obtained by linear programming model, which costs the minimum, was composed of 68% corn, 25.07% soy beans, 4% wheat bran, 0.5% fish powder, 0.5% calcium diphosphate, 0.1% lysine, 0.32% methionine, 0.3% limestone, and 0.3% salt, in addition to soybean oil, vitamins and minerals.

Methodology

1. Data: The study relied on preliminary data through field visits to breeders and the official institutions responsible for this sector to collect data on production costs and current agricultural prices. The data was collected through a questionnaire that addressed costs, productions and technical issues for the production season of 2018 in Swaida, Syria.

2. Sample selection: The sample included 104 broiler farmers in Swaida, Syria. The sample size was calculated according to the following equation (Glenn, 1992; Yamane, 1967):

$$n = \frac{N}{1 + N(e)^2}$$

Where:

N: Size of the study population, 210 broiler farms (Central Agr Extension, 2016).

e: Precision level, ±7%.

n: Sample size

3. Statistical analysis software: IBM SPSS Statistics 23 and Excel Solver were used to process and analyze the data in order to solve optimization problems in mathematical programming.

4. Statistical analysis method: The study adopted a number of methods of descriptive statistics such as arithmetic mean and graphs, in addition to the following:

- ♦ Financial analysis: Through using a number of evaluation indicators (Atieh, 2008; Al-Thenyian &Sultan, 1993; Al-Atwan &al-Homsi, 2011), as follows:
  - Net income= gross revenues- gross expenses
  - Operating ratio= gross operating expense/net sales
  - Profitability of invested SYP: (average of net annual income/project's average expenses) * 100%
  - Net Profit margin= Gross Product – variable expenses
  - Revenues to expenses ratio
  - The break-even point= fixed costs/(total sales revenues-variable expenses) * 100
  - Variable assets turnover rate= gross domestic production/value of variable expenses
  - Turnover time of variable assets= 365/ variable assets turnover

- ♦ Quantitative Analysis for Management: Using one of the Operations Research methods, which is linear programming. It is categorized under Decision Science, which has different common models. It is used to show the optimal use of production activities in light of the available resources and potentials. In other words, it is used for solving problems through finding optimal combinations of activities in order to achieve one of the following targets: maximization or minimization (Benjamin, 1985; Beneke, 1982&; Hazell & Norton, 1986). Linear programming is expressed as follows (maximization or minimization):

$$(\text{maximization})\text{or }(\text{minimization})\ z = \sum_{j=1}^{n} c_j x_j$$

Subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \geq\leq b_i \quad \text{for} \quad i = 1,2,\ldots\ldots,m$$

$$x_j \geq 0 \qquad \text{for} \quad j = 1,2,\ldots\ldots,n$$

Z:	Objective function	bi:	Available resources
C:	Coefficients of the objective function	n:	Number of activities
aij:	Coefficient Constraints	m:	Number of constraints
Xj	Activities (nominal variables)	Xj ≥ 0:	Non-negativity condition

Results and Discussion:

First: Economic Evaluation of broiler Farming Projects in Swaida:

1.1 Calculating total expenses:

The analysis of the questionnaire that was distributed to the sample of the study revealed that the expenses of producing 1kg of chicken meat is calculated, and the average expenses of five annual production cycles (2 summer cycles and 3 winter cycles) is calculated, noting that the average production cycle, starting from chicks rearing till marketing, lasts 45 days. The sum of fixed annual expenses were found to be 1,413,046.37 SYP for an average-sized farm, 720 m², that has an average number of chickens of 6478 chickens in summer cycle and 6541 chickens in winter cycle. Labor costs account for 74.15% of the fixed annual expenses, followed by the farm's rent of 23.30%. The fixed annual expenses for one production cycle amounted to 282,609.27 SYP per farm as detailed inTable1.

Table 1:

Average of fixed annual expenses for broiler farms according to the sample of the study

Item	Value SYP	Percentage %
1.Annual Labor Costs	1,047,805.98	74.15
2.Rent	329,230.77	23.3
3.License Fees	29,600.96	2.09
4.Income Tax (Finance)	1,403.85	0.1
5.Service Fees (Municipality)	639.42	0.05
6.Fees of Union's Supervision	1,403.85	0.1
7.Buildings and Land Tax	2,961.54	0.21
Total Fixed Annual Expenses	1,413,046.37	100
Total Fixed Annual Expenses per Production Cycle per Farm	282,609.27	

Source: Analysis of the questionnaire

Meanwhile, the average variable expenses for the summer production cycle amounted to 8,093,997.49 SYP per farm, and the average variable expenses for the winter production cycle amounted to 9,052,893 SYP per farm as detailed in Table 2.

Table 2:

The average variable expenses for the production cycle of broiler farms according to the sample of the study

Item	Summer Production Cycle		Winter Production Cycle	
	Value SYP	Percentage %	Value SYP	Percentage %
Chicks	1,524,139.42	18.83	1,656,163	18.29
Bedding	173,050.48	2.14	227,096.2	2.51
Water	94,721.15	1.17	100,701	1.11
Coal	226,130.77	2.79	820,873.1	9.07
Electricity	119,305.29	1.47	172,430.3	1.9
drugs and Vaccine	386,464.42	4.77	415,422.1	4.59
Feed	5,550,820.57	68.58	5,640,842	62.31
Cleaning and Disinfecting Substances	19,365.38	0.24	19,365.38	0.21
Total	8,093,997.49	100	9,052,893	100

Source: Analysis of the questionnaire

Table 3 shows the details of both variable and fixed total expenses. The analysis of the table reveals that variable expenses account for 97% of gross expenses in both summer and winter cycles. The total expenses for one chicken were found to be 1,441.87 SYP in summer, 1,568.79 SYP in winter, while the cost of producing 1kg of chicken meat was found to be 776.11 SYP in summer, and 782.57 SYP in winter.

Table 3:

Gross expenses for both summer and winter production cycles

Expenses	Summer Production Cycle		Winter Production Cycle	
	Value SYP	Percentage %	Value SYP	Percentage %
Variable Expenses SYP/Farm	8,093,997.49	96.63	9,052,893.16	96.95
Fixed Expenses SYP/Farm	282,609.27	3.37	282,609.27	3.03
Gross Expenses SYP/Farm	8,376,606.76	100	9,335,502.44	100
Number of Chicks	6,478		6,541	
number of deaths	668		590	
*Actual number of chicks	5,810		5,951	
Cost of One Chicken	1,441.87		1,568.79	
Amount of Meat in Ton	10.79		11.93	
Amount of Meat in Kg	10,793.08		11,929.33	
Cost of Producing 1 Kg of Meat	776.11		782.57	

Source: Analysis of the questionnaire

*: Actual number of chicks = total number of chicks - number of deaths

1.2 relative importance of variable expenses items:

The analysis of both summer and winter cycles' items, shows that feed expenses came first in terms of relative importance of broiler farms' variable production expenses in the governorate of Swaida, accounting for 62% of gross variable expenses in summer cycle and 69% in winter cycle. Meanwhile, expenses for purchase of chicks account for 18.19% of the gross variable expenses, while healthcare costs, such as vaccine and drugs, account for 5% of gross variable expenses in both summer and winter cycles. The costs of coal, which is used in heating, constitute 9% of the gross variable expenses in winter and only 3% of the gross variable expenses in summer.

1.3 Revenues and financial evaluation indicators:

Revenues included both main revenue from meat production and secondary revenue from by-products (poultry litters). Table 4 shows that the total revenue in the production cycle generated from the main product, meat, amounted to 8,361,202 SYP per farm. The main product's materiality constituted 99% of the gross revenues, while the total revenues from the sale of remnants amounted to 50,942.3 SYP per farm according to the study sample. Moreover, it was found within the sample that broiler farms' projects in the governorate of Swaida did not show a real economic feasibility according to all of the economic indicators as demonstrated by the following marginal values. First, the positive value of both the net income indicator, 35,537.47 SYP per farm, and the gross margin, 318,146.7 SYP per farm per production cycle. Second, the ratio of revenues to costs was found to be 1.004%, where the higher the ratio is than 1%, the more successful the project is. Third, operating ratio was found to be 0.996%, where the lower the ratio is than 1%,the more economically acceptable the project is. Last, the profitability of the invested

SY Preached 0.42% as shown in Table 4.

The financial evaluation indicators showed that these projects were not feasible for winter operating cycles and appeared with particularly negative values: net income, gross margin, and revenue on sales ratio. This is due to the fact that the projects afford, in addition to all their operating costs, an increase in the heating costs due to the high fuel prices, the high prices of chicks, in addition to the high consumption of medicines and vaccines in the winter cycles, as a result of the chances of the spread of pandemic diseases, all with relative stability at the sale prices of broilers. Referring to Table 2, and by comparing the details of the costs of the production process inputs, the difference between the variable costs for the summer and winter operating cycles is clear.

Table 4.

Revenues and the financial assessment indicators on the examined sample

Indicators	Summer Production Cycle	Winter Production Cycle
Total revenue from meat	8,361,202	7,606,063
Total revenue from poultry litters	50,942.3	102,653.9
Sum	8,412,144	7,708,716
Net income (net revenues of the farm)	35,537.47	-1,626,786
Operation rate	0.996	1.21
The profitability of invested Syrian Pound (Lira)	0.42	-17.4
Gross margin	318,146.7	-1,344,177
Revenues rate to costs	1.004	0.83
Break point	0.89	-0.21
The average of variable asset turnover	1.039	0.85
The timeframe of variable asset	351.2	428.65
Return on sales ratio	0.42	-21.1

Source: Analysis of the questionnaire

Second: The Mathematical Formula of the Linear Programming Model of the Optimal Feed Mix

This section deals with the study and analysis of the mathematical linear programming model of the optimal feed mix in the event of introducing any available feed component. This is accomplished through the study of the Starting ration, then the study of the Final ration, provided that the proposed feed mixes achieve the minimum and maximum limits of the required food components. (see annexes 1 & 2). The nutrition model will be adopted following two periods where the difference will be noticed in the amount of protein and energy that are needed to be available in the feed mix. The starting feed aged from one day- 4 weeks and had the energy of 3200 k cal ME/ kg of feed and 23% protein, while the final feed aged from 4 weeks was used for marketing, with 3200 k cal ME/ kg feed energy and 19% protein (Al-Rabee'i, 2013).

2.1. The linear mathematical analysis of the feed mix:

The linear mathematical programming model used to produce the optimal broiler chicken consists of;

A. Objective function: to minimize the cost of the bush feed mix to the minimum level, as follows;

$$\min z = 165x1 + 125x2 + 127x3 + 250x4 + 70x5 + 200x6 + 280x7 + 285x8 + 200x9 + 500x10 + 300x11 + 350x12 + 300x13 + 250x14 + 550x15 + 233.2x16 + 792x17 + 1496x18 + 50x19 + 1980x20$$

B. Constraints: These are the nutrition values that should be available in the bush.

	Constraints	Constraints Equations
1	All ingredients	$X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 + X10 + X11 + X12 + X13 + X14 + X15 + X16 + X17 + 1X18 + X19 + X20 = 1000$
2	Barley maximum level	$X2 \leq 250$
3	Bran maximum level	$X5 \leq 100$
4	Grains maximum level	$X1 + X2 + X3 + X4 + X5 \leq 500$
5	legumes maximum level	$X13 + X14 \leq 100$
6	Corn oil maximum level	$X15 \leq 30$

	Constraints	Constraints Equations
7	Salt maximum level	$X19 \leq 3.5$
8	Salt & vitamins maximum level	$X20 \leq 3$
9	Fats maximum level	$2.5X1 + 1.8X2 + 3.8X3 + 2.9X4 + 3X5 + 2.5X6 + 0.8X7 + X8 + 2.9X9 + 2.8X10 + 10X11 + 10X12 + 95X15 \leq 7000$
10	Humidity maximum level	$11X1 + 11X2 + 12X3 + 11X4 + 11X5 + 9X6 + 10.4x7 + 10x8 + 7x9 + 10x10 + 8x11 + 5x12 \leq 10000$
11	Fibers maximum level	$3X1 + 5.5X2 + 2.2X3 + 2X4 + 11X5 + 1.3X6 + 7X7 + 3.9X8 + 5X9 + 14X10 + X11 + 2X12 \leq 7000$
12	Ash maximum level	$1.6X1 + 2.4X2 + 1.8X3 + 1.7X4 + 6.1X5 + 2X6 + 5.7X7 + 5.6X8 + 9.3X9 + 7.1X10 + 21.7X11 + 71.8X12 \leq 5000$
13	Phosphorus maximum level	$0.31X1 + 0.36X2 + 0.28X3 + 0.13X4 + 1.15X5 + 0.19X6 + 0.65X7 + 0.62X8 + 0.16X9 + 0.42X10 + 2.95X11 + 14X12 + 0.18X13 + 0.11X14 + 18.7X16 \leq 1000$
14	Calcium maximum level	$0.05X1 + 0.03X2 + 0.02X3 + 0.04X4 + 0.14X5 + 0.29X7 + 0.27X8 + 0.38X9 + 2.02X10 + 5.02X11 + 30X12 + 0.2X13 + 0.52X14 + 22X16 \leq 1500$
15	Sodium maximum level	$0.07X1 + 0.02X2 + 0.01X3 + 0.01X4 + 0.3X5 + 0.03X6 + 0.24X7 + 0.34X8 + 0.3X10 + 0.46X12 \leq 250$
17	Lysine maximum level	$0.39X1 + 0.4X2 + 0.26X3 + 0.25X4 + 0.61X5 + 1.29X6 + 2.69X7 + 2.69X8 + 1.73X9 + 1.09X10 + 4.83X11 + 0.87X12 + 1.34X13 + 1.73X14 + 100X17 \leq 1400$
18	Methionine maximum level	$0.26X1 + 0.18X2 + 0.18X3 + 0.35X4 + 0.23X5 + 2.79X6 + 0.62X7 + 0.67X8 + 2.22X9 + 1.86X10 + 2.32X11 + 0.29X12 + 0.59X13 + 0.41X14 + 100X18 \leq 600$
19	Di calcium phosphate maximum level	$X16 \leq 20$
20	Corn oil minimum level	$X15 \geq 20$
21	Legumes minimum level	$X13 + X14 \geq 30$
22	Salt minimum level	$X19 \geq 2.5$
23	Vitamins & salt minimum level	$X20 \leq 3 \geq 2.5$
24	Fats minimum level	$2.5X1 + 1.8X2 + 3.8X3 + 2.9X4 + 3X5 + 2.5X6 + 0.8X7 + X8 + 2.9X9 + 2.8X10 + 10X11 + 10X12 + 95X15 \geq 4000$
25	Humidity minimum level	$11X1 + 11X2 + 12X3 + 11X4 + 11X5 + 9X6 + 10.4x7 + 10x8 + 7x9 + 10x10 + 8x11 + 5x12 \geq 5000$
26	Fibers minimum level	$3X1 + 5.5X2 + 2.2X3 + 2X4 + 11X5 + 1.3X6 + 7X7 + 3.9X8 + 5X9 + 14X10 + X11 + 2X12 \geq 3000$
27	Ash minimum level	$1.6X1 + 2.4X2 + 1.8X3 + 1.7X4 + 6.1X5 + 2X6 + 5.7X7 + 5.6X8 + 9.3X9 + 7.1X10 + 21.7X11 + 71.8X12 \geq 2000$
28	Phosphorus minimum level	$0.31X1 + 0.36X2 + 0.28X3 + 0.13X4 + 1.15X5 + 0.19X6 + 0.65X7 + 0.62X8 + 0.16X9 + 0.42X10 + 2.95X11 + 14X12 + 0.18X13 + 0.11X14 + 18.7X16 \geq 500$
29	Sodium minimum level	$0.07X1 + 0.02X2 + 0.01X3 + 0.01X4 + 0.3X5 + 0.03X6 + 0.24X7 + 0.34X8 + 0.3X10 + 0.46X12 \geq 100$
30	Lysine minimum level	$0.39X1 + 0.4X2 + 0.26X3 + 0.25X4 + 0.61X5 + 1.29X6 + 2.69X7 + 2.69X8 + 1.73X9 + 1.09X10 + 4.83X11 + 0.87X12 + 1.34X13 + 1.73X14 + 100X17 \geq 800$
31	Methionine minimum level	$0.26X1 + 0.18X2 + 0.18X3 + 0.35X4 + 0.23X5 + 2.79X6 + 0.62X7 + 0.67X8 + 2.22X9 + 1.86X10 + 2.32X11 + 0.29X12 + 0.59X13 + 0.41X14 + 100X18 \geq 300$
32	Dicalcium phosphate minimum level	$X16 \geq 10$
33	Non negative entry	$X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, X13, X14, X15, X16, X17, X18, X19, X20 \geq 0$

However, the starting and final mix differ from each other in the value of protein and energy, thus the constraint identified between the two bush feed mix is the ratio of energy to protein and so the constraint entryis as follows:

Starting	minimum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \geq 139000$
	maximum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \leq 139130$
Final	minimum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \geq 168000$
	maximum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \leq 168421$

2.2. Application of linear programming model:

The percentage of the main ingredients of the optimal mix. Table 5 shows the quantities of the main ingredients of the proposed feed mix, and the proportion of each in the optimal mix with the cost, as follows;

- The starter: the amount of barley was the highest with respect to the ingredients of the mix as it reached 250kg, 25% of the mix, followed by sunflower meal which amounted to 145.61kg, around 14.56 % of the mix, then soybean meal which amounted to 140.8 kg, around 14.08% of the mix. As for wheat, corn, bran, lentil, soybean meal and corn oil, all amounted to 48%. The quantities of each in the mix were as follows respectively; 133.3, 16.6, 100, 100, 63.8 and 23.7 kg at about 13.3%, 1.66%, 10%, 10%, 6.38% and 2.37%. For feed supplements (dicalcium, food salt, as well as vitamins and mineral salts), they were in the order of 20, 3.5 and 2.5 kg at 2%, 0.35% and 0.25% respectively.
- The finisher: The amount of yellow corn amounted to 203.282 kg around 20.33% which is the highest value in the mix, then barley at 196.71 kg with 19.67% of the mix, then sunflower meal and soybean meal 48% which amounted to 148 kg of the mix each reached 14.8%. As for bran, lentil, soybean meal and corn oil, they amounted to 44%, as follows 100, 100, 56.95, 20.5 kg(10%, 10%, 5.65% and 2.05% respectively). As for the supplementary feed (dicalcium, food salt, vitamins and mineral salts), they were in the order of 20, 3.5, 2.5 with 2%, 0.35%, 0.25% respectively.

Table 5.

Results of using linear mathematical programming model in the proposed feed mix.

Ingredients	*Price SYP	Amount		Amount in percent		Cost	
		Final	Starting	Final	Starting	Final	Starting
Wheat	165	0	133.34	0	13.33	0	22,000.95
Barley	125	196.72	250.00	19.67	25.00	24,589.78	31,250
Corn	127	203.28	16.66	20.33	1.67	25,816.78	2,115.94
Sorghum	250	0	0	0	0	0	0
Coarse bran	70	100	100	10	10	7,000	7,000
Corn gluten 60%	200	0	0	0	0	0	0
Soybean meal 44%	280	56.95	140.84	5.70	14.08	15,946.82	39,434.92
Soybean meal 48%	285	148.13	63.82	14.81	6.38	42,216.98	18,188.27
Sunflower meal	200	148.40	145.61	14.84	14.56	29,679.48	29,122.01
Sesame meal	500	0	0	0	0	0	0
Fish meal	300	0	0	0	0	0	0
Bone meal	350	0	0	0	0	0	0
Chickpeas	300	0	0	0	0	0	0
Lentil	250	100	100	10	10	25,000	25,000
Corn oil	550	20.52	23.73	2.05	2.37	11,285.95	13,052.84
Dicalcium phosphate	233.20	20	20	2	2	4,664	4,664
Lysine	792	0	0	0	0	0	0
Methionine	1496	0	0	0	0	0	0
Salt	50	3.50	3.50	0.35	0.35	175	175
Vitamins and salt	1980	2.50	2.50	0.25	0.25	4950	4950
Total		1000	1000	100	100	191,324.80	196,953.93

Reference: These calculations were obtained using excel solver.

3.2. The cost of the optimal feed mix:

Tables 5 & 6 show the cost of one ton of feed according to the results of the applied model and it was compared with breeders' cost of one ton of feed. The gross cost of one ton of the proposed starting feed mix when applying the linear programming model was about 196,953.93 SYP per ton. While the average price per ton for the starter feed mix used by the breeders was about 235,000 SYP. There is a decrease in cost about 38,046.066 SYP per ton, i.e. the cost decreased by about 16.1988%.

In the other hand, the gross cost per ton of the proposed final mix through the application of the linear programming model is about 191,324.8 SYP per ton, while the average price per ton for the final feed mix used by the breeders was about 230,000 SYP, i.e. there is a decrease in cost about 38,675.2 per ton, as the cost decreased by about 16.8%.

Table 6:

The cost per ton of the mix obtained from the linear programming model and the mix used by the breeders

The Feed Mix Cost	Starting	Final
Used by the breeders SYP/ton	235,000	230,000
The mix obtained by using the linear programming model	196,953.934	191,324.8
The difference between the two mix	38,046.066	38,675.2
The difference in percent	16.1898	16.8

Source: These results were calculated based on the previous table, from the questionnaire

Third: The Impact of Feed Cost Decreased by 16% on the Indicators of the Financial Evaluation

The results of the study showed that the rearing projects of broilers chicken in the governorate of Sweida with respect to the sample did not show any actual economic feasibility in terms of all economic indicators (summer production cycle), as what the boundary values of their indicators have shown. On the other hand, indicators showed the infeasibility of these projects during the winter production cycle of the sample. The results of applying the linear programming model revealed that the total cost per ton of the starting feed was about 196,953,934 SYP, i.e. the cost per one ton decreased by approximately 16.1898%. The total cost per ton of the proposed final feed mix obtained by the application of the linear programming model amounted to about 191,324.8 SYP, thus reducing the cost per ton by about 16.8%. However, in this section, we will tackle the impact of feed cost decrease by 16% (mean) on the computerized financial evaluation indicators of the sample, through studying the impact of feed cost decrease on the variable costs and the stability of the fixed computerized variables of the sample, in addition to the macro fixed revenues (from meat and remnants).

3.1.The impact of feed cost decrease by 16% on the indicators of the financial evaluation on the variable costs:

Table 7 shows that during the summer production cycle when comparing the ratio of the feed cost vis-à-vie the variable costs, it was found that it decreased from 68.58% to 64.71%, and from 62.31% to 58.14% during the winter production cycle. However. The cost of rearing chicks increased from 18.83% to 21.15% from the variable costs during the summer production cycle, and from 18.29% to 23.32% during the winter production cycle. Moreover, the cost of the variable costs has decreased from 8,093,997.5 SYP of the chicken farm during the summer production cycle to 7,205,866 SYP, and the cost also decreased from 9,052,893.1 SYP to 8,150,358.4 of the chicken farm during winter production cycle.

Table 7.

Variable costs for both summer and winter production cycle, after the cost of the obtained feed mix by using the linear program has decreased by 16%

The Cost of the Farm During the Cycle in SYP	The obtained feed mix by using the linear program			
	Summer Cycle		Winter Cycle	
	Value	%	Value	%
1. Chicks	1,524,139	21.15	1,656,163	20.32

The Cost of the Farm During the Cycle in SYP	The obtained feed mix by using the linear program			
	Summer Cycle		Winter Cycle	
	Value	%	Value	%
2. Bedding	173,050.5	2.4	227,096.2	2.79
3. Water	94,721.15	1.31	100,701	1.24
4. Coal	226,130.8	3.14	820,873.1	10.07
5. Electricity	119,305.3	1.66	172,430.3	2.12
6. Drugs and vaccines	386,464.4	5.36	415,422.1	5.1
7. Feed	4,662,689	64.71	4,738,307.3	58.14
8. Sterilizing and cleaning materials	19,365.38	0.27	19,365.38	0.24
The total of variable costs	7,205,866	100	8,150,358.4	100

Source: Computed based on the questionnaire data and the results of the proposed linear programming model.

3.2.The impact of feed cost decrease by 16% on the indicators of financial evaluation:

By analyzing table 8, we notice that the indicators of the financial evaluation with respect to the sample has improved. The positive value for each net income index is 35,537.47 SYP/farm; while the gross margin is 318,146.7 SYP/farm per one production cycle of the normal feed mix which has increased to 921,477.99 while the gross margin amounted to 1,206,278.42 SYP/farm to the mix obtained by using the linear programming model. However, the value of the revenues ratio to costs has increased to more than 1% from 1.004% to 1.123% and this shows that the project is more profitable when it jumps above 1%. Moreover, the operation ratio has decreased from 0.996% to 0.890% and this indicates that the project is feasible. Nevertheless, the profitability of the invested pound rose from 0.42% to 12.302%. Moreover, the ratio of return on sales increased from 0.42% to 10.954%, and the turnover of variable assets decreased from 351.2 to 312.66 days as shown in table 8.

Although the financial indicators in winter cycles when using mixes extracted by mathematical linear programming models were better, there were clear losses as the financial indicators did not show the economic feasibility of these projects. This is due to several main factors imposed by the production process during the winter cycles, ***the most important of which are:***

- High heating costs (hydrocarbons or coal).
- High mortality rates due to prevailing weather factors.
- High prices of chickens during winter cycles.

Table 8.

Impact of the feed cost decrease by 16% on the computerized indicators of the financial evaluation of the sample.

Indicator	Summer Cycle		Winter Cycle	
	Normal mix	Linear programming mix	Normal mix	Linear programming mix
Net income (of the farm)	35,537.47	921,477.99	-1,626,786	-726,442.056
2. Operation ratio	0.996	0.890	1.21	1.094
3. The profitability of the invested Lira	0.42	12.302	-17.4	-8.612
4. Gross margin	318,146.7	1,206,278.04	-1,344,177	-441,642.014
5. The ratio of revenues to costs	1.004	1.123	0.83	0.914
6. Break point	0.89	0.236	-0.21	-0.645
7. The average of variable assets	1.039	1.167	0.85	0.946
8. The cycle duration of the variable assets	351.2	312.66	428.65	385.911
9. Return on sales ratio	0.42	10.954	-21.1	-9.424

Source: Computed based on the questionnaire data and the results of the proposed linear programming mode

Conclusion

The results of applying the linear programming model showed the following:

1. For the starter: The amount of barley reached the highest value of the mix ingredient. It amounted to 250kg, i.e. 25% of the mix, then sunflower meal which reached 145.61 kg by about 14.56% of the mix, followed by soybean meal 44%, 140.8 kg, i.e. 14.08% of the mix. The total cost per ton of the proposed starting mix when applying the linear programming model amounted to about 196,953,934 SYP, i.e. the cost decreased by approximately 16.1988%.

2. For the finisher: The amount of yellow corn reached the highest value of the mix ingredients. It amounted to 203.282 kg, i.e. 20.3% of the mix, then barley which reached 196.71 kg, i.e. 19.67% of the mix, followed by sunflower meal and soybean meal which amounted to 48%, each for 148 kg, i.e. 14.8%. However, the total cost of one ton of the final feed that was obtained using the linear programming model amounted to 191,324.8 SYP, i.e. which decreased by 16.8% approximately.

3. Through analyzing and studying the impact of feed cost decrease by 16% on the computed financial indicators of the sample, it is noted that the value of the variable costs has decreased to 7,206,866 SYP/farm during the summer production cycle and to 8,150,358.4 SYP/farm during the winter production cycle.

4. The indicators of the financial evaluations has improved at the sample level, as the value of the gross and net margin has increased to 921,477.999 and 1,206,278.042 SYP/farm of the obtained mix by using the linear programming model. The ratio of revenues to costs jumped above 1% to reach 1.123 %, and the operation cost increased to 0.890% whereas the profitability of the invested Lira increased to 12.302%. The net profit margin increased to 10.954 % and the turnover of the variable assets decreased to 312.66 days.

5. The results obtained showed that they are consistent with what was presented in the research of studies that used the linear programming methodology to determine optimal feeds; The use of programming models in the selection of feed mixtures reduced the cost of feed and this is shown in Al-Aboudi (2014), Nath & Ashok (2014), Almasad et.al.(2011) and Al-Deseit (2009).

Recommendations

1. The possibility to apply the linear programming model in the poultry sector, in order to identify the optimal feed mix at the lowest cost. Provide a model of the mix which fits the price fluctuation and the provision of the feed ingredients at the lowest cost.

2. The availability of different feed ingredients that provide nutrients and the needed conditions in the composition of the feed mix, which can be replaced partially in different quantities and percentages, or can be replaced in full, in the event of high prices, or lack of availability of such materials.

3. The study recommends the application of the linear programming model in identifying the optimal and civil mix and its cost in the poultry sector, as well as to expand the introduction of other feed ingredients in the mix if available.

4. The need for applying the proposed mixture in reality, to review its nutritional suitability for broilers.

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Annexes

Annex 1:

The Chemical Analysis of the Feed Ingredients in the Proposed Mix

symbol	Ingredient	*Price SYP	Calories c	Protein %	Fats %	Fibers %	Ca %	P %	Na %	Lysine %	Methionine %
x1	Wheat	165	3120	11.5	2.5	3	0.05	0.31	0.07	0.39	0.26
x2	Barely	125	2640	11	1.8	5.5	0.03	0.36	0.02	0.4	0.18
x3	Yellow corn	127	3350	8	3.8	2.2	0.02	0.28	0.01	0.26	0.18
x4	White corn	250	3210	11.4	2.9	2	0.04	0.13	0.01	0.25	0.35
x5	Coarse bran	70	1300	15.7	3	11	0.14	1.15	0.3	0.61	0.23
x6	Yellow corn gluten 60%	200	3720	62	2.5	1.3	0	0.19	0.03	1.29	2.79
x7	soybean meal 44%	280	2230	44	0.8	7	0.29	0.65	0.24	2.69	0.62
x8	Soybean meal 48%	285	2440	48.5	1	3.9	0.27	0.62	0.34	2.69	0.67
x9	Sunflower meal	200	2320	45	2.9	5	0.38	0.16	0	1.73	2.22
x10	Sesame meal	500	2210	43.5	2.8	14	2.02	0.42	0.3	1.09	1.86

symbol	Ingredient	*Price SYP	Calories c	Protein %	Fats %	Fibers %	Ca %	P %	Na %	Lysine %	Methionine %
x11	Fish powder	300	3190	72.3	10	1	5.02	2.95	0	4.83	2.32
x12	Bones powder	350	2150	50.4	10	2	30	14	0.46	0.87	0.29
x13	Chickpeas	300	2756	20.8	-	-	0.2	0.18	0	1.34	0.59
x14	Lentil	250	2647	23.5	-	-	0.52	0.11	0	1.73	0.41
x15	Corn oil	550	8800	-	95	-	-	-	-	-	-
x16	deCalcium PhoSYPhate	233.2	-	-	-	-	22	18.7	-	-	-
x17	Lysine	792	-	-	-	-	-	-	-	100	-
x18	Methionine	1496	-	-	-	-	-	-	-	-	100
X19	Salt	50	-	-	-	-	-	-	-	-	-
x20	Vitamins and salt	1980	-	-	-	-	-	-	-	-	-

Source: Al-Aboudi (2014), NRC (1994), Al-Ribat & Hassan (1986) (*): prices for 2018.

Annex2:

Maximum and Minimum Limits of the Most Important Nutrition Elements

Ingredients	Maximum limit	Minimum limit
Fats	%7	%4
Humidity	%10	%5
Fibers	%7	%3
Ash	%5	%2
Phosphorus	%0.1	%0.5
Calcium	%1.5	%0.7
Sodium	%0.25	%0.1
Lysine	1.4	%0.8
Methionine	%0.6	%0.3
Phosphorus/ Calcium	%2	%1.5
Vegetable oils	%3	%2
legumes	%10	%0.03
Grains	%50	-
Salt Kg/Tons	3.5	2.5
Vitamins and Salts Kg/Tons	3	2.5
Di calcium phosphate Kg/ Tons	20	10
Barley	%25	-
Bran	%10	-

Source: Al-Kassar (2012), Al-Rabee›i(2013)

Reliability and Failure Probability Functions of the Consecutive-k-out-of-m-from-n: F System with Multiple Failure Criteria

اقتران موثوقية و اقتران احتمال فشل النظام التتابعي k-out-of-m-from-n: F متعدد معايير الفشل

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Abstract:

The consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria consists of n sequentially ordered components (K= (k_1, k_2,..., k_H), m = (m_1, m_2,..., m_H)). The system fails if among any m_1, m_2,..., m_H consecutive components there are at least k_1, k_2,..., k_H components in the failed state. In this paper, the ordinary consecutive-*k*-out-of-*m*-from-*n*: F system played a pivotal role in achieving the reliability and failure probability functions of the consecutive-**k**-out-of-**m**-from-*n*: F linear and circular system with multiple failure criteria. We proved that the failure states of the multiple failure criteria system is a union of all failure state of the consecutive-k_i-out-of-m_i-from-*n*: F system, while the functioning state is an intersection of the functioning states of the consecutive-k_i-out-of-m_i-from-*n*: F system for $i \in \{1,2,....H\}$. The maximum number of failed components of the functioning consecutive **k**-out-of-**m**-from-*n*: F system with multiple failure criteria is computed.

Keywords: Consecutive *k*-out-of-*m*-from-*n*: F system, Reliability function, Failure probability function

ملخص:

يتكون النظام التتابعي k-out-of-m-from-n: F متعدد معايير الفشل من n من المكونات أو الأجزاء، والذي يفشل إذا حدث انه خلال أي من m_1, m_2,..., m_H المكونات المتتابعة يفشل خلالها على الأقل k_1, k_2,..., k_H عدد من المكونات.

في هذا البحث تم استنتاج اقتران الكثافة الاحتمالي للموثوقية والفشل لهذا النظام من خلال استخدام طبيعة ومكونات النظام العادي ذو الشرط الوحيد k-out-of-m-from-n: F، فلقد أثبتنا أن حالات الفشل للنظام التتابعي متعدد معايير الفشل هو فعليا اتحاد لحالات الفشل للنظام التتابعي ذو الشرط الوحيد(k_i-out-of-m_i-from-*n*: F) ، أما حالات العمل للنظام التتابعي متعدد معايير الفشل فهي تقاطع حالات العمل للنظام التتابعي ذو الشرط الوحيد (k_i-out-of-m_i-from-*n*: F) ، خلال هذا كله، تم حساب العدد الأقصى للمكونات أو الأجزاء التي ممكن أن تفشل بحيث يبقى النظام ككل في حالة العمل.

الكلمات المفتاحية: النظام التتبعي ذو الشرط الوحيد، اقتران موثوقية ، احتمال فشل النظام التتبعي.

Notation

L(C): Linear (circular)

i.i.d.: Independent and identically distributed

$\mathbb{I}_j^i$ $= \{i, i+1, ..., j\}$ $1 \le i < j \le n$

$P(\mathbb{I}_n^1)$: The power set of $\mathbb{I}_n^1$.

$X = \{x_1, x_2, ..., x_j\}$: A subset of $\mathbb{I}_n^1$, such that $x_i < x_h$ for all $1 \le i < h \le j \le n$

f_n^t: The composite function t times, where $f_n(x) = x \bmod_n + 1 : x \in \mathbb{I}_n^1$

$d_X = (d_1^X, d_2^X, ..., d_j^X)$: The rotations of the set $X = \{x_1, x_2, ..., x_j\}$, such that $d_i^X \ge 1$ is the minimum integer number such that $f_n^{d_i^X}(x_i) = x_{i+1}$, for i=1,2,…, j-1, and $f_n^{d_j^X}(x_j) = x_1$, where $n = \sum_{i=1}^{j} d_i^X$.

$M_r^{L(C)} = (k_r - 1)\overline{[n/m_r]} + s_r^{L(C)}$ where

$$s_r^C = \begin{cases} b_r - m_r + k_r - 1 & b_r \ge m_r - k_r + 1 \\ 0 & \text{otherwise} \end{cases}$$

$$s_r^L = \begin{cases} k_r - 1 & b_r \ge k_r - 1 \\ b_r & b_r < k_r - 1 \end{cases},$$ and

$b_r = n \bmod m_r$.

$d_X^t = (d_{j-t+1}^X, ..., d_j^X, d_1^X, ..., d_{j-t}^X)$ $t \in \mathbf{Z}$, where

$d_X^0 = d_X^j, d_X^{j+s} = d_X^s, t \le j$

$\overline{X}$: The complement of the set X.

$|X|$: The cardinality of the set X.

$\equiv, \sim$: Equivalence relations

$i \underset{j}{\oplus} r$ $= (i+r) \bmod j$, unless if $i+r=nj$ then $i \underset{j}{\oplus} r = j$, when $n \in \mathbf{Z}$

$p_i(q_i)$: The reliability (unreliability) of the i^{th} components

$R(X)(F(X)) = p_X = \prod_{i \in \overline{X}} p_i \prod_{j \in X} q_j$, the reliability (unreliability) of the set X.

$\Psi_{L(C)}^{k,m,n}\left(\Theta_{L(C)}^{k,m,n}\right)$: The collection of all failure (functioning) states of the consecutive-k-out-of-m-from-n: F linear (circular) system.

k,m: Vectors representing failure criteria in the system, ($\mathbf{k} = (k_1, k_2, ..., k_H)$, $\mathbf{m} = (m_1, m_2, ..., m_H)$)

$\Psi_{L(C)}^{\mathbf{k},\mathbf{m},n}\left(\Theta_{L(C)}^{\mathbf{k},\mathbf{m},n}\right)$: The collection of all failure (functioning) states of the consecutive-**k**-out-of-**m**-from-n: F linear (circular) system

p_n^s $= p(n,s) = p^{n-s} q^s$

$\lceil n \rceil$: The greatest integer number of n.

1. INTRODUCTION

Over time, the requirements of people's life have become very complicated, requiring highly complex and sophisticated systems. Consequently, this urges the engineers to insure that these systems will perform the required functions. In this context, they developed theorems for such systems, and applied available results for all type of systems, including system reliability, optimal system design, component reliability importance, and reliability bounds.

The consecutive-k-out-of-m-from-n: F system model has interested many engineers since 1985. It is a generalization of the famous consecutive-k-out-of-n: F system which had been used in the telecommunication networks, spacecraft relay stations, vacuum systems in accelerators, oil pipeline systems, photographing nuclear accelerators, microwave stations of a telecom network, etc. Kontoleon (1980) was the first person to introduce the system under the name "r-successive-out-of-n:F system", then Chiang & Niu (1981) created the name "consecutive k-out-of-n: system". Bollinger (1982) presented a direct combinatorial method for determining the system failure probability. Shanthikumar (1982) and Derman et al. (1982) provided a recursive algorithm to evaluate the reliability of the system. Bollinger (1986) introduced a simple and easily programmed algorithm for calculating a table of the coefficients for the failure probability polynomials, associated with the system where the components are i.i.d. Eryılmaz (2009) studied the reliability properties of the consecutive k-out-of-n systems when the components are arbitrarily dependent. Chao M. T, Lin G.D. (1984) and Fu & Hu (1987) studied the reliability of the consecutive k-out-of-n: F system using the Markov chain. Lambiris and Papastavridis (1985) and Nashwan (2015) introduced exact formulas for the reliability of the linear and circular system with i.i.d. components. Dăuş and Beiu (2015) computed the lower and upper bound of the system with a large number of components, and Gökdere (2016) provided a simple way for determining the system failure probability.

The consecutive-k-out-of-m-from-n: F system consists of n components. The components are connected linearly or circularly. The system fails if at least k failed components are included in any m consecutive components. Such a system model was applied in many applications, such as radar detection, quality control and inspection procedures. Tong (1985) was the first to mention the system, while Griffith (1986) introduced the system formally. Afterwards, many researchers studied the system's reliability, failure functions, reliability bounds, optimal system design, etc. Sfakianakis et al. (1992) provided explicit algorithms for the reliability of consecutive-k-out-of-m-from-n: F linear and circular system when the components are i.i.d. Papastavruds & Higsiyama et al. (1995), studied a special case when k=2 with unequal component probabilities. Malinowski & Preuss (1995, 1996) evaluated the reliability of the system with independent component which failure probability may be unequal. Habib et al. (2007) used the total probability theorem to evaluate the reliability of a special case of multi-state consecutive *k*-out-of-*r*-from-*n*: G system. Amirian et al. (2019) provided an algorithm for the exact reliability function of the consecutive k-out-of-r-from-n: F system.

Koutras (1993) provided upper & lower bounds for the reliability of a (linear or circular) consecutive-*k*-out-of-*m*-from-*n*: F system with unequal component failure probabilities. Habib et al. (2000) and Radwan et al. (2011) introduced new bounds for the reliability of the consecutive *k*-out-of-*r*-from-*n*: F system.

The linear consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria consists also of n connected linearly components. $\mathbf{k}$ and $\mathbf{m}$ are failure integer vector, $\mathbf{k}=\{k_r \mid 1\le r\le H\}$ and $\mathbf{m}=\{m_r \mid 1\le r\le H\}$, where $m_r \le m_{r+1} \le n$, and $k_r \le m_r$. The system fails if at least one group of m_r consecutive components exists in which at least k_r components are in a failed state, for any $1\le r\le H$. One can easily demonstrate that, for any r, if $k_r=1$, then it becomes a series system.

Actually Levitin (2004) generalized the linear consecutive-*k*-out-of-*r*-from-*n*: F system to the case of multiple failure criteria, and evaluated only the reliability of the system. He used an extended universal moment generating function, and introduced motivated examples as applications, such as the radar system, combat system and the heating system as shown in figure 1.

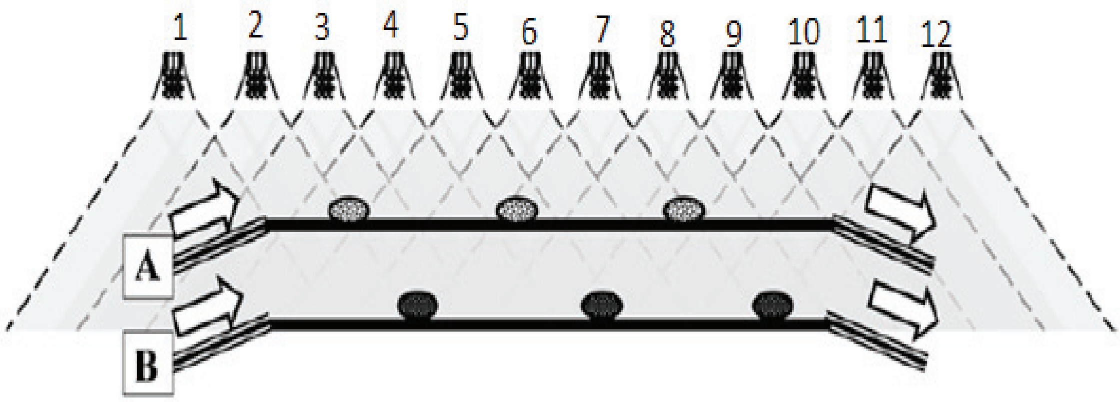

Fig. 1:
The heating system (The linear consecutive-(2,3)-out-of-(3,5)-from-12: F system).

The system consists of 12 heaters, which should provide a certain temperature along the 2 heating lines A and B. The temperature through the two lines at any point is determined by the cumulative effects of the 3 and 5 adjacent heaters, respectively. The heaters cannot provide a certain temperature, if at least 2 out of 3 consecutive heaters, or at least 3 out of 5 consecutive heaters are in the failure state, i.e. the whole system is in failure condition.

In this paper, we developed the classification technique of Nashwan (2018) for the ordinary consecutive-*k*-out-of-*m*-from-*n*: F system (one failure criteria) to compute the exact reliability and failure probability functions of the consecutive-*k*-out-of-*m*-from-*n*: F system with multiple failure criteria. We also developed some conditions to determine the failure and the working states of the system.

In the following section, we study the failure and the functioning states of the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria using the simple one failure criteria system properties (the circular consecutive-*k*-out-of-*m*-from-*n*: F system). This in turn paved the way to classify them again within the linear type in the third section. Moreover, we computed the maximum possible number of failure components whenever the system is in the functioning state. Finally, an algorithm to find the reliability and failure probability functions of the linear and circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria is obtained. Through all, the system and the components are satisfied by the following:

- The state of the component and the system are either "functioning" or "failed".
- All the components are mutually statistically independent.

2. The circular consecutive-*k*-out-of-*m*-from-*n*: F system with multiple failure criteria

Consider the components indices of the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria are denoted by I_n^1, $P(I_n^1)$ is the failure space of the components indices. The system is represented by the set $X=\{x_1,x_2,...,x_j\}\in P(I_n^1)$, which consists of all the indices of the failed components.

Fix $r\in I_H^1$, then X is a failure state of the system, if there is a m_r consecutive components (whether in the functioning or in the failure state), and among them k_r indices included in *X*, i.e. there is a k_r failed components from *X* among any m_r consecutive components. Moreover, if $Y\in P(I_n^1)$ such that $X\subseteq Y$, then *Y* is also a failure state. Actually, *X* is a failure state of the simple one criteria circular consecutive-k_r-out-of-m_r-from-*n*: F system.

Conversely, if X is a functioning state of the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria, if it does not hold any failure criteria of the failure vector , i.e. for all $r\in I_H^1$ X is a functioning state in the simple one criteria circular consecutive-k_r-out-of-m_r-from-*n*: F system. In this context, we claim the following:

Claim: $\Psi_C^{\mathbf{k},\mathbf{m},n}=\bigcup_{r=1}^{H}\Psi_C^{k_r,m_r,n}$, and $\Theta_C^{\mathbf{k},\mathbf{m},n}=\bigcap_{r=1}^{H}\Theta_C^{k_r,m_r,n}$.

Proof: If $X\in\Psi_C^{\mathbf{k},\mathbf{m},n}$, then *X* hold at least one failure criteria of the failure vectors, i.e. there exists $r\in I_H^1$ such that X contains at least k_r (indices) failed components among m_r consecutive components, which implies that, X is a failure state of the simple circular consecutive-k_r-out-of-m_r-from-n: F system, i.e. $X\in\Psi_C^{k_r,m_r,n}$, which means that $X\in\bigcup_{r=1}^{H}\Psi_C^{k_r,m_r,n}$. Conversely is trivial.

For the functioning states, if $X\in\Theta_C^{\mathbf{k},\mathbf{m},n}$, then it does not hold any criteria of the failure vectors, i.e. for all $r\in I_H^1$, $X\in\Theta_C^{k_r,m_r,n}$ which implies that $X\in\bigcap_{r=1}^{H}\Theta_C^{k_r,m_r,n}$. Conversely is trivial.

Again, fix any $r\in I_H^1$, Nashwan (2018) partition $P(I_n^1)$ of the consecutive-k_r-out-of-m_r-from-*n*: F linear (circular) system into finite pairwise disjoints classes on the form $[X]=\{f_n^\alpha(X):\alpha\in\mathbf{Z}\}$, where $f_n:I_n^1\to I_n^1$ is a bijection function, such that $f_n(x)=(x \bmod n)+1$ for any $x\in I_n^1$. He explained that, for any two states $X,Y\in P(I_n^1)$, $[X]=[Y]$ if there exists $t=1,2,...,j$ such that $d_Y=d_X^t$. Moreover, he classified $P(I_n^1)$ into two sub collections, $\Psi_{L(C)}^{k_r,m_r,n}$ and $\Theta_{L(C)}^{k_r,m_r,n}$, and computed $M_r^{L(C)}$, the maximum possible failed components, when the consecutive-k_r-out-of-m_r-from-*n*: F linear (circular) system is in the functioning state. For example, in the consecutive-3-from-4-out-of-9: F circular system, the set $X=\{1,2,4,5\}$, for simply $X=1245$, means that, the only failed components are the components with the indices 1,2,4, and 5. The class $[1245]=\{1245,2356,....,1349\}\in\Psi_C^{3,4,9}$, and $[1245]=[2389]$, since $d_{1245}=(1,2,1,5)=d_{2389}^2$, while $M^C=(3-1)\overline{[9/4]}+0=2\times 2=4$. Moreover, $X=1245\in\Psi_C^{(3,k_2),(4,m_2),9}$ for any integer numbers k_2,m_2, where $k_2\le m_2\le 9$. The next lemma adds more details on the failure and the functioning states of the system.

Lemma 2.1: If the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria is represented by $X=\{x_1,....,x_j\}\in P(I_n^1)$ such that $j\geq k=\min_{1\leq r\leq H}\{k_r\}$, define $S_C^X(m_r)=\left\{S_i^X=\sum_{t=0}^{k_r-2} d_{i\oplus_j t}^X : i\in I_j^1\right\}$, then X is a failed state, if there exists $(i,r)\in I_j^1\times I_H^1$ such that $S_i^X \prec m_r$,.

Proof: If there exists $(i,r)\in I_j^1\times I_H^1$, such that $S_i^X=\sum_{t=0}^{k_r-2} d_{i\oplus_j t}^X \prec m_r$; hence the total steps on the circle to walk through the k_r distinct failed components $\{x_i,x_{i\oplus_j 1},....,x_{i\oplus_j k_r-1}\}\subseteq X$ is less than m_r steps, i.e. k_r distinct failed components among m_r consecutive components, hence the system fails.

Lemma 2.2: For any two states $X,Y\in P(I_n^1)$ represent the circular consecutive-k-out-of-m-from-n: F system with multiple failure criteria, such that $Y\in[X]$,

- If $X\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$, then $Y\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$.
- $R(Y)=F(Y)=p_{f_n^\alpha(X)}$ for some $\alpha\in\mathbf{Z}$.
- If the components are i.i.d., then $R(Y)=R(X)=p_n^{|X|}$ and $F(Y)=F(X)=p_n^{|X|}$.

Proof:

- If $X\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$, and $Y\in[X]$, then there exists $t\in I_j^1$ such that $d_Y=d_X^t$, which implies that $S_C^X(m_r)=S_C^Y(m_r)$, i.e. $Y\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$.
- If $Y\in[X]$, then there exists $\alpha\in\mathbf{Z}$, such that $Y=f_n^\alpha(X)$, hence , $R(Y)=p_Y=p_{f_n^\alpha(X)}$. Also $F(Y)=p_Y=p_{f_n^\alpha(X)}$
- If the components are i.i.d., then $|X|=|Y|$, apply 2, $R(X)=p_n^{|X|}=p_n^{|Y|}=R(Y)$

Note: The reliability and the failure probability functions of the class $[X]$ are $\mathsf{R}[X]=\sum_{Z\in[X]} R(Z)=\sum_{Z\in[X]} p_Z$, and $\mathsf{F}[X]=\sum_{Z\in[X]} F(Z)=\sum_{Z\in[X]} p_Z$ respectively.

3. The linear consecutive-*k*-out-of-*m*-from-*n*: F system with multiple failure criteria

In this section, the procedure for the system reliability and failure evaluation is based on connecting the 1st and n components in the linear consecutive-**k**-out-of-**m**-from-*n*: F system, and treating the system as a circular type. However, this connection creates more failure states than that in the linear system, i.e. $\Psi_L^{\mathbf{k},\mathbf{m},n}\subseteq\Psi_C^{\mathbf{k},\mathbf{m},n}$ and $\Theta_L^{\mathbf{k},\mathbf{m},n}\supseteq\Theta_C^{\mathbf{k},\mathbf{m},n}$; hence our duty is to separate these extra failures states from $\Psi_C^{\mathbf{k},\mathbf{m},n}$ and add them to $\Theta_C^{\mathbf{k},\mathbf{m},n}$ to compute $\Theta_L^{\mathbf{k},\mathbf{m},n}$.

Lemma 3.1: If the linear consecutive-**k**-out-of-**m**-from -*n*: F system with multiple failure criteria is represented by the set $X=\{x_1,...,x_j\}\in P(I_n^1)$, such that $j\geq k=\min_{1\leq r\leq H}\{k_r\}$, define $S_L^X(m_r)=\left\{S_i^X=\sum_{t=0}^{k_r-2} d_{i+t}^X : i\in I_{j-(k_r-1)}^1\right\}$, then X is a failed state if there exists $(i,r)\in I_{j-(k_r-1)}^1\times I_H^1$, such that $S_i^X\prec m_r$.

Proof: The proof is the same as in *lemma 2.1* but the condition $i\in I_{j-(k_r-1)}^1$ is to exclude the effects of the connection between the 1st and the nth components.

For example, the state $\{169\}\in[127]\in\Psi_C^{(2,3),(3,5),9}$, since $S_C^{169}(3)=\{1,3,5\}, S_3^X=1\leq 3$, while $\{169\}\notin\Psi_L^{(2,3),(3,5),9}$, and $S_L^{169}(3)=3,5\geq 3$, and $S_L^{169}(5)=8\geq 5$

Lemma 3.2: Consider the linear (circular) consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria is in the functioning state, and $M^{L(C)}$ is the maximum number of failed components, then $M^{L(C)} = \min_{1\le r\le H}\left\{M_r^{L(C)}\right\}$.

Proof: Assume that $M^{L(C)} > M_i = \min_{1\le r\le H}\left\{M_r^{L(C)}\right\}$, then WLOG, the consecutive-k_i-out-of-m_i-from-n: F linear (circular) system is in the failure state, which implies that the consecutive-**k**-out-of-**m**-from-*n*: F linear (circular) system is in the failure state, which contradicts the assumption.

4. The proposed algorithm

If *j* is the number of the failed components in the consecutive-**k**-out-of-**m**-from-*n*: F linear and circular system with multiple failure criteria, and $k = \min_{1\le r\le H}\{k_r\}, M^{L(C)} = \min_{1\le r\le H}\left\{M_r^{L(C)}\right\}$, then the failure $\mathsf{F}_j^{L(C)}$ and reliability $\mathsf{R}_j^{L(C)}$ functions are given using the following:

- ♦ For j=0,1, …, k-1, all states are in the functioning state, then $\mathsf{R}_j^{L(C)} = \binom{n}{j} p_n^{n-j}$ and $\mathsf{F}_j^{L(C)} = 0$
- ♦ Using (lemma 3.2), For j=k, k+1, …, $M^{L(C)}$, find $d_X = \left(d_1^X, d_2^X, ..., d_j^X\right)$.
- ♦ Using Nashwan (2018), find the corresponding $X \in P\left(\mathsf{I}_n^1\right)$ and compute $[X]$
- ♦ Foreach $r \in \mathsf{I}_H^1$, compute $S_C^X(m_r) = \left\{S_i^X : i \in \mathsf{I}_j^1\right\}$. If there exists $S_i^X \in S_C^X(m_r)$ such that $S_i^X \prec m_r$, then $X \in \Psi_C^{\mathbf{k},\mathbf{m},n}$, otherwise $X \in \Theta_C^{\mathbf{k},\mathbf{m},n}$ (*lemma 2.1*).
- ♦ For the linear system,
  - \- If $X \in \Theta_C^{\mathbf{k},\mathbf{m},n}$ then $[X] \in \Theta_L^{\mathbf{k},\mathbf{m},n}$
  - \- If $X \in \Psi_C^{\mathbf{k},\mathbf{m},n}$, check $S_L^Y(m_r) = \left\{S_i^Y : i \in \mathsf{I}_{j-(k_r-1)}^1\right\}$ for all $Y \in [X]$.(*lemma 3.1*)
  - \- Add all Y that does not hold the condition of lemma 3.1 to $\Theta_L^{\mathbf{k},\mathbf{m},n}$.
  - \- The $\Theta_L^{\mathbf{k},\mathbf{m},n}$ consists of $\Theta_C^{\mathbf{k},\mathbf{m},n}$ and all Y does not hold the condition of *lemma 3.1.* in 5.3.
- ♦ Finally, it is obvious that $\mathsf{R}_j^{L(C)}\left(\mathsf{F}_j^{L(C)}\right)$, the summation of the reliability (failure) function of the classes $[X] \in \Theta_{L(C)}^{\mathbf{k},\mathbf{m},n}\left(\Psi_{L(C)}^{\mathbf{k},\mathbf{m},n}\right)$, where $|X| = j$.
- ♦ Using (*lemma 3.2*) again, for $j > M^{L(C)}$, all states are failed, hence $\mathsf{F}_j^{L(C)} = \binom{n}{j} p_n^{n-j}$ and $\mathsf{R}_j^{L(C)} = 0$.
- ♦ The reliability function of the system is $\mathsf{R}_{L(C)} = \sum_{j=0}^{n} \mathsf{R}_j^{L(C)}$, while the failure function is $\mathsf{F}_{L(C)} = \sum_{j=k}^{n} \mathsf{F}_j^{L(C)}$.

Example 4.1:

The reliability and the failure functions of the (2,3)-out-of-(3,5)-from-9: F linear and circular system

$$M^{L(C)} = 3$$

For j=0, 1 all states are in the functioning states, i.e. $\mathsf{F}_j^{L(C)} = 0, \quad \mathsf{R}_j^{L(C)} = \binom{n}{j} p_n^j$

For j=2

$d_{\{1,2\}} = (1,8) \Rightarrow S_C(3) = \{1,8\}, S_C(5) = \{9\}$

$[12] = \{12,23,34,45,56,67,78,89,\underline{19}\} \in \Psi_C^{(2,3),(3,5),9}$,

$S_L^{\{19\}}(2) = \{8\} \Rightarrow \{19\} \in \Theta_L^{(2,3),(3,5),9}$

$d_{\{1,3\}} = (2,7) \Rightarrow S_C(3) = \{2,7\}$,

$S_C(5) = \{9\}, W_1^{\{18\}}(2) = W_1^{\{29\}}(2) = 7 \Rightarrow$

$[13] = \{13,24,35,46,57,68,79,\underline{18},\underline{29}\} \in \Psi_C^{(2,3),(3,5),9}$,

$S_L^{\{18\}}(2) = S_L^{\{29\}}(2) = \{8\} \Rightarrow \{18,29\} \in \Theta_L^{(2,3),(3,5),9}$

$d_{\{1,4\}} = (3,6) \Rightarrow S_C(3) = \{3,6\}, S_C(5) = \{9\} \Rightarrow$

$[14] = \{14,25,36,47,58,69,17,28,39\} \in \Theta_C^{(2,3),(3,5),9}$

$d_{\{1,5\}} = (4,5) \Rightarrow S_C(3) = \{4,5\}, S_C(5) = \{9\} \Rightarrow$

$$[15] = \left\{\begin{matrix}15,26,37,48,59,16,27,\\ 38,49\end{matrix}\right\} \in \Theta_C^{(2,3),(3,5),9}$$

$\mathsf{F}_2^C = 18p_9^2 \qquad \mathsf{R}_2^C = 18p_9^2$

$\mathsf{F}_2^L = 15p_9^2 \qquad \mathsf{R}_2^L = 21p_9^2$

For j=3

$$[123]=\{123,234,345,456,567,678,789,189,129\}\in\Psi_C^{(2,3),(3,5),9}$$

$$[124]=\{124,235,346,457,568,679,178,289,139\}\in\Psi_C^{(2,3),(3,5),9}$$

$$[125]=\left\{\begin{matrix}125,236,347,458,569,167,\\ 278,389,\underline{149}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{149\}}(5)=\{8\}\Rightarrow\{149\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[126]=\left\{\begin{matrix}126,237,348,459,156,267,\\ 378,489,\underline{159}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{159\}}(5)=\{8\}\Rightarrow\{159\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[127]=\left\{\begin{matrix}127,238,349,145,256,367,\\ 478,589,\underline{169}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{159\}}(5)=\{8\}\Rightarrow\{169\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[128]=\left\{\begin{matrix}128,239,134,245,356,467,\\ 578,689,179\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9}$$

$$[135]=\left\{\begin{matrix}135,246,357,468,579,168,\\ 279,138,249\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9}$$

$$[136]=\left\{\begin{matrix}136,247,358,469,157,268,\\ 379,\underline{148},\underline{259}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{148\}}(5)=S_L^{\{259\}}(5)=\{7\}\Rightarrow$$
$$\{148,259\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[137]=\left\{\begin{matrix}137,248,359,146,257,368,\\ 479,\underline{158},\underline{269}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{158\}}(5)=S_L^{\{269\}}(5)=\{7\}\Rightarrow\{159,269\}\in\Theta_L^{(2,3),(3,5),9}$$

$$\mathsf{F}_3^C=81p_9^3 \qquad \mathsf{R}_3^C=3p_9^3$$
$$\mathsf{F}_3^L=74p_9^3 \qquad \mathsf{R}_3^L=10p_9^3$$

For $j\geq 4$ all states are in the failure states, hence $\mathsf{F}_j^{L(C)}=\binom{9}{j}p_9^{9-j}$, $\mathsf{R}_j^{L(C)}=0$, then, the reliability functions of the linear and the circular systems

$$\mathsf{R}_L=\sum_{j=0}^{9}\mathsf{R}_j^C=p_9^0+9p_9^1+21p_9^2+10p_9^3$$
$$\mathsf{R}_C=\sum_{j=0}^{9}\mathsf{R}_j^C=p_9^0+9p_9^1+18p_9^2+3p_9^3,$$

and the failure probability functions of the linear and the circular systems

$$\mathsf{F}_L=\sum_{j=2}^{9}\mathsf{F}_j^C=15p_9^2+74p_9^3+126p_9^4$$
$$+126p_9^5+81p_9^6+36p_9^7+9p_9^8+p_9^9$$

$$\mathsf{F}_C=\sum_{j=4}^{9}\mathsf{F}_j^C=18p_9^2+81p_9^3+126p_9^4$$
$$+126p_9^5+81p_9^6+36p_9^7+9p_9^8+p_9^9$$

CONCLUSION

In this paper, we proposed an algorithm to find the reliability and the failure probability functions of the consecutive-**k**-out-**m**-from-*n*: F linear and circular system with multiple failure criteria. In this context, we determined the collections of all failure and the functioning states, where the collection of failure states of the linear type is a sub collection of the circular one. Moreover, we computed the maximum possible number of the failed components in the working consecutive-**k**-out-**m**-from-*n*: F linear and circular systems with multiple failure criteria.

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Data Mining Techniques for Prediction of Concrete Compressive Strength (CCS)

تقنيات التنقيب في البيانات للتنبؤ بالقوة الانضغاطية الخرسانية

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Abstract

The main aim of this research is to use data mining techniques to explore the main factors affecting the strength of concrete mix. In this research, we are interested in finding some of the factors that influence the high performance of concrete to increase the Concrete Compressive Strength (CCS) mix. We used Waikato's Knowledge Analysis Environment (WEKA) tool and algorithms such as K-Means, Kohonen's Self Organizing Map (KSOM) and EM to identify the most influential factors that increase the strength of the concrete mix. The results of this research showed that EM is highly capable of determining the main components that affect the compressive strength of high performance concrete mix. The other two algorithms, K-Means and KSOM, were noted to be an advanced predictive model for predicting the strength of the concrete mix.

Keywords: Data Mining, Concrete Compressive Strength (CCS), K-means, EM Algorithm, Kohonen's Self-Organizing Map (KSOM) , Clustering.

ملخص:

هدف البحث الرئيس، هو استخدام تقنيات استخراج البيانات لاكتشاف العوامل الرئيسية التي تؤثر في قوة مزيج الخرسانة. إن جل اهتمامنا في هذا البحث، هو إيجاد بعض العوامل التي تؤثر في الأداء العالي للخرسانة لزيادة مزيج قوة ضاغطة الخرسانة. لتحقيق هذا الهدف، استخدمنا أداة Waikato's Environment Analysis Environment (WEKA) وخوارزميات مثل K-Means وخريطة كوهن ذاتية التنظيم (KSOM) و EM لتحديد العوامل الأكثر تأثير والّتي تزيد من قوة مزيج الخرسانة. أظهرت نتائج هذا البحث أن EM يظهر أهمية كبيرة لتحديد المكونات الرئيسية التي تؤثر في قوة الضغط للمزيج الخرساني عالي الأداء. بينما تعد الخوارزميات K-Means و KSOM نموذجًا تنبؤيًا متقدمًا لقوة الخلطة الخرسانية.

كلمات مفتاحية: تعدين البيانات، قوة الضغط الخرسانية EM ،K-means،(CCS) خوارزمية ، خريطة كوهن ذاتية التنظيم (KSOM).

INTRODUCTION

Technical engineers and laboratories are required to obtain and test the strength and the accuracy of concrete. Testing modeling at the laboratory is both, time and cost consuming (Agrawal V. and Sharma A., 2010) as it includes most of the ingredients or components that are required for designing concrete. The traditional approaches focus on understanding and modeling the effects of the components on the strength of concrete (Chen L. and Wang T. S., 2010). Nowadays, the situation has changed with the rapid spread of information technology. In the recent years, different techniques of Artificial Intelligence (AI) and Data Mining were used to predict the main factors that affect the concrete strength. Recently, there has been many applications and approaches that are based on Artificial Intelligence and Data Mining in Civil Engineering (Chen L. and Wang T. S., 2010; Jain et al., 1994; Flood I., and Kartam N., 1994).

Concrete is the major building material that is used around the world. Concrete mainly consists of three basic components that are mixed in measured proportions. These components are, water, portland cement and aggregate (gravel, sand and rock). They all form a solid material called concrete. Concrete is well known for its high compressive strength, impermeability, fire resistance, durability and abrasion resistance.

There are several factors that affect the strength of High Performance Concrete (HPC). Ration of water to cement may be considered the main factor, but it is also induced by the components of the concrete like cement, blast furnaces slag, fly ash, water, super plasticizer, coarse aggregate, fine aggregate and age.

Using Data Mining will provide advice, assistance and indication of signs to enhance Concrete Compressive Strength (CCS) by finding the main factors that influence the compressive strength of concrete and its high performance.

This study focuses on identifying the list of components that affect Concrete Compressive Strength (CCS) by using data mining Algorithms to assist in predicting and identifying the main necessary components to identify high performance compressive strength of concrete.

This study is based on publicly available resources of UCI Machine Learning Repository with eight parameters and one output. We used three different data mining algorithms. These algorithms are K-Means, Kohonen's Self Organizing Map (KSOM) and EM and applied them on the dataset. According to the analysis of the data and the results, the most accurate result is achieved by EM for predicting the key components that affect the compressive strength of concrete. On the other hand, K-Means and KSOM can be used as an effective tool for predicting concrete compressive strength.

In this paper, we start with the literature review of the research papers (section 2). An overview of data mining techniques in civil engineering is then presented in section3. In Section 4, we explain in details the methodological approaches used throughout this study, followed by a discussion regarding the findings of this research (Section 5). Finally, a summary and conclusion are presented in Section 6.

Literature Review

In the recent years, Artificial Intelligence played essential roles in solving problems that are difficult to address through the traditional programming or human experts. Researcher used data mining and ANN for solving many problems in many fields such as, tourism, finance, banking, aerospace, airplane navigation, life insurance, automotive, terrorism, defense, fault detection in electric and electronics, telecommunications, entertainment, control systems in industry, automotive of manufacturing, transportation (Arciszewski, et al, 1994), agriculture (Abuzir Y., 2018), smart cities, civil engineering, medicine, image processing, robotics, speech recognition and information securities.

Data Mining Technique (DMT) applications have become more numerous and more important in many areas. By using DMT, we are able to see a transformation and obtain new knowledge or skills in many fields, as well as allow or plan for a certain possible new future applications (Shu et al, 2011).

In the literature Review, there are different approaches and studies that focus on finding the appropriate properties for designing concrete and predicting the Concrete Compressive Strength (CCS) using Artificial Intelligence techniques.

Ozcan et al., in their research proposed Artificial Neural Networks to predict long-term compressive strength of silica fume concrete (Ozcan et al, 2009). Another researcher used neural network for predicting Concrete Compressive Strength (CCS) with different water/cement ratios. In the input layer of the neural network model, they used the following five input parameters: water/binder ratio, binder/sand ratio, metakaolin percentage, superplasticizer percentage, and age. The proposed neural network model predicts the compressive strength of mortars only (Saridemir M., 2009).

Neural Network model are based on four input parameters prediction models used for predicting compressive strength of concrete. The input layer employed the following four parameters: Water-to-binder ratio, cement content, curing conditions, and age (Yaprak et al, 2011).

(Tinoco et al., 2010) used Data Mining technique as a prediction model for uniaxial compressive strength (UCS) of JG materials. They showed their model are able to identify with high accuracy the complex relationship between the UCS of JG material and its contributing factors.

Another approach is based on combining conventional method with the artificial intelligence method to design a predictive model for a concrete compressive strength. The results showed that their model is accurate and suitable for predicting the compressive strength development (Liu G. and Zheng J., 2019).

DATA MINING IN CIVIL ENGINEERING

An Overview of Data Mining and Weka

Data mining is a process or a technique of applying different algorithms on a large dataset for extracting beneficial information or knowledge.

Intelligent tools are required to apply data mining techniques to manipulate datasets.

Data mining is often used as a combination of intelligent and unconventional sciences like business analytics, mathematics, logic, statistics, artificial intelligence, machine learning and artificial neural networks (Mohammed, 2016), (Abuzir Y. and Baraka A.M, 2019).

The analytic techniques used in data mining often share or use the following Data Mining algorithms (Brown, 2012), (Patel et al., 2014):

- Classification
- Clustering
- Association
- Prediction
- Sequential patterns
- Decision trees

Data mining involves five steps: Data selection, data cleaning, data transformation, pattern evaluation and knowledge presentation and finally decisions / use of discovered knowledge as shown in the Figure 1

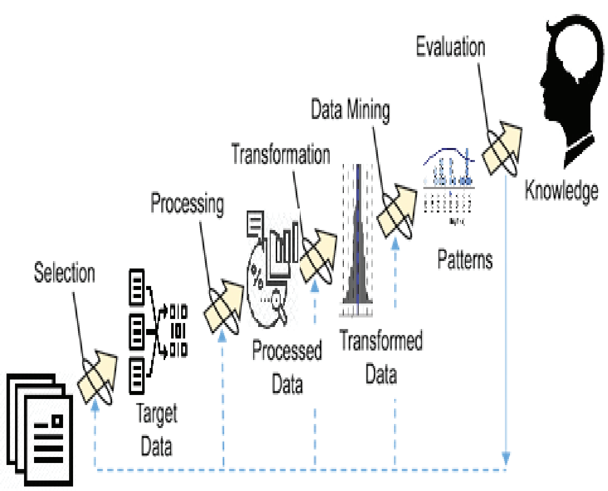


Figure 1

The main steps in Data mining

WEKA is abbreviation for Waikato's Knowledge Analysis Environment. It is an open source tool developed by the University of Waikato in New Zealand. WEKA is a Java based tool that involves many open source data mining and machine learning algorithms. WEKA has the following features (Alka, et al. 2017):

- Data processing tools.
- Classification, clustering algorithms and association.
- User interface and graphical interface.
- WEKA data mining and machine learning tools

The Use of Data Mining in Civil Engineering

Nowadays, a lot of data and information related to civil engineering field are available on online repositories of the research centers. Researchers can use this information and apply different data analysis to obtain important information to support their research papers. They can use data mining techniques in many areas of Civil Engineering.

In the field of civil engineering, many research papers apply different approaches of Data Mining and Artificial Neural Network (ANN) technologies (Deepa et al. 2010; Guneyisi, et al., 2009; Topcu I.B, Sarıdemir M., 2007). Different studies applied data mining techniques and ANN the following areas of civil engineering (Kaplinski, et al., 2016; Topcu, et al., 2009):

- Predicting properties of conventional concrete (Guneyisi, et al., 2009).
- Predicting high performance compressive strength of concretes (Ozcan et al, 2009; (Nikoo, et al., 2015), (Han, et al., 2019; Young et al., 2018).
- Concrete mix proportions (Topcu I.B, Sarıdemir M. , 2007) [15] (Young et al., 2018).
- Predict the concrete durability (Yaprak, et al., 2009) [5] (Pann et al, 2003).
- Modeling of material behavior (Bock et al, 2019),
- Detection of structural damage (Fanga, et al., 2005),
- Structural system identification (Chou, et al., 2014),
- Structural optimization (Tanyildizi, H. 2009),
- Structural control, ground water monitoring (El-Kholy, A. M. 2019),
- Prediction of settlement of shallow foundation (Pann, et al. 2003)

MATERIALS AND METHODS

Most of the previous studies attempted to investigate, study and model the effects of the components on the strength of the concrete. In the recent years, new approaches utilized Artificial Intelligence (AI) and Data Mining techniques to predict the main factors that affect the concrete strength.

The main contributions of our approach is twofold. First, it focuses on using all the different components that compose the concrete, to study the main factors that influence the high performance of the concrete, to increase the Concrete Compressive Strength (CCS) mix. Second, we try to find a better and more accurate prediction model for CCS. We can summarize our contributions in the following points:

- The study uses three different algorithms K-Means, Kohonen's Self Organizing Map (KSOM) and EM.
- The study determines which is the best algorithm that can be used to identify the main factors that influence the strength of concrete.

The study identifies the best algorithm that can be used as an advanced prediction model for the strength of concrete mix.

This research utilized data mining techniques to predict the key components that affect the strength of concrete. WEKA tool provides us with different tools to analyze the dataset and apply different algorithms such as EM, Kohonen's Self Organizing Map (KSOM) and K-Means. The following paragraphs and subsections discuss the characteristics of the datasets and algorithms used in this study. It discusses in details the methodological approach used to develop the prediction model of the main key factors that affect the compressive strength of concrete.

Data Sets

Compressive strength concrete dataset from UCI Machine learning Repository (Yeh I. C., 1998) is used as the experimental data sets of 1030 cases. In the data set, there are eight input parameters and one output value Concrete Compressive Strength (CCS). These parameters are cement, blast furnaces slag, fly ash, water, super plasticizer, coarse aggregate, fine aggregate and age. For the first seven parameters, we use kg/m3 and for the eighth parameter age, we use number of days for the laboratory test of the concrete sample.

We obtained the statistical analysis using Weka to create Table 1 and represent it using graphs in Figure 2. Table 1 lists a general statistical information on the eight factors. These statistics are computed by WEKA. The table shows the maximum, minimum , the average, the mean and the Standard deviation for each factors. Weak supports users though two methods to split data.

The first method is training and supplied test set. The second method is a percentage split and these groups are not included with each other during the training phase. To conduct the statistical analysis of the datasets, we divided the dataset into two groups: A training set (721 samples) amounting to70%, and a testing set (309 samples) amounting to 30% of the group. After splitting the data into training and testing sets, the statistical analysis and data mining algorithms were applied to present the results.

Table 1

Concrete Strength Data Sets Components Ranges (WEKA)

Name of Component	Maximum (kg/m3 mixture)	Minimum (kg/m3 mixture)	Average Value (kg/m3 mixture)	Mean	SDV
Cement	540	102	321	281.16	104.50
Blast Furnace	359.40	0	179.7	73.896	86.279
Fly Ash	200.10	0	100.05	54.188	63.997
Water	247	121.75	184.375	181.56	21.354
Superplasticizer	32.20	0	16.1	6.205	5.974
Coarse Aggregate	1145	801	973	972.91	77.754
Fine Aggregate	992.60	594	793.3	773.58	80.176
Age of testing	365 days	1 day	183 days	45.662	63.17

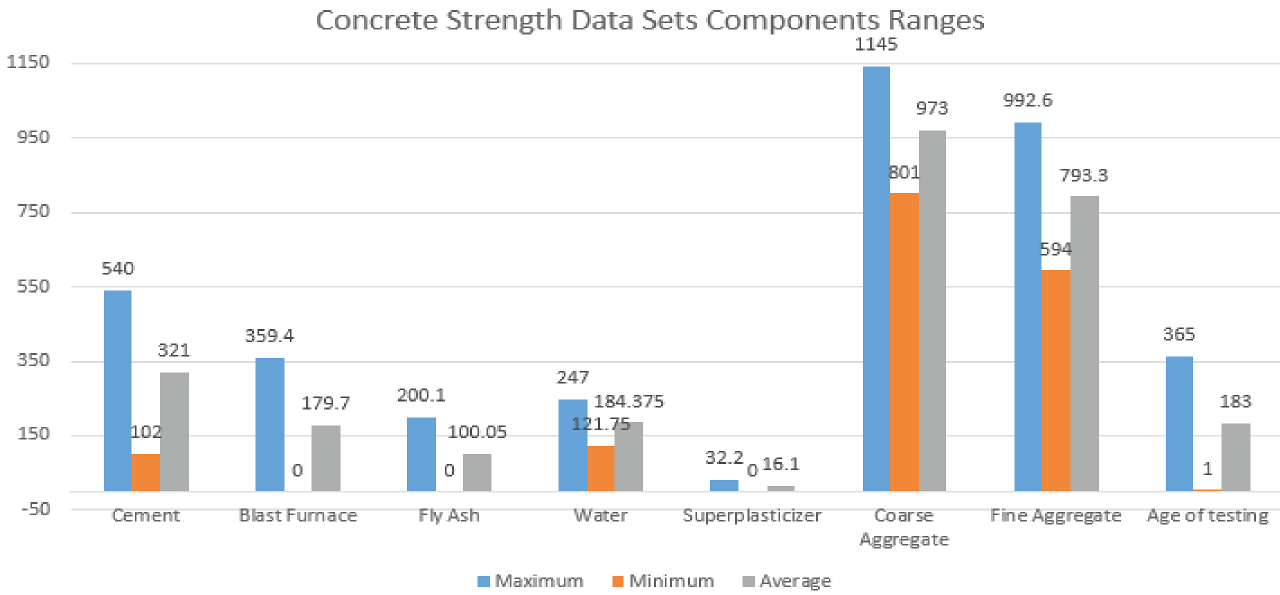


Figure 2.

Concrete Strength Data Sets Components Ranges

DATA MINING ALGORITHMS

This section presents the different machine learning algorithms used in finding the main factors that affect the compressive strength of the concrete. EM is one of the clustering algorithms used in data mining. It uses two iterative steps called E-step and M-step:

- ♦ E-step, where each object assigned to the most likely cluster(centroids).
- ♦ M-step, where the model (centroids) are recomputed (Least Squares Optimization).

Another algorithm is Kohonen Self-Organizing Map (KSOM). It is one of the most adopted neural network in unsupervised learning. (Fernando, 2015).

K-means algorithm is a clustering algorithm, given the data <x1, x2,…,xn> and K, assign each xi to one K clusters, C1…Ck, minimizing equation 1 (Khedr et. al, 2014), equation (1) used to find Sum of Squared Error (SSE)

$$SSE = \sum_{j=1}^{K} \sum_{x_i \in C_j} \left\| x_i - \mu_j \right\|^2. \qquad (1)$$

Where

K is the number of desired clusters

is mean over all points in cluster Cj.

The following Algorithm is used to apply K-Means:

1. Set randomly

2. Repeat until convergence:

- Assign each point xi to the cluster with closest mean
- Calculate the new mean for each cluster (equation 2)

$$\mu j = \frac{1}{|C_j|} \sum_{x_i \in C_j} x_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Figure 3 presents a schematic illustration of prediction mechanisms using the three machine-learning algorithms of simple K-Means, KSOM and EM.

We utilized the EM, KSOM and K-means algorithms for finding the main components in concrete mix that affect the compressive strength of concrete. The study applied these algorithms with different configurations of both, the algorithms and the dataset. Then the study analyzed the results along with an evaluation of the different configurations of the results. The simplest approach is to find the parameter that minimizes scores of the different parameters like Standard Deviation (STD) and Root Mean Squared Error (RMSE).

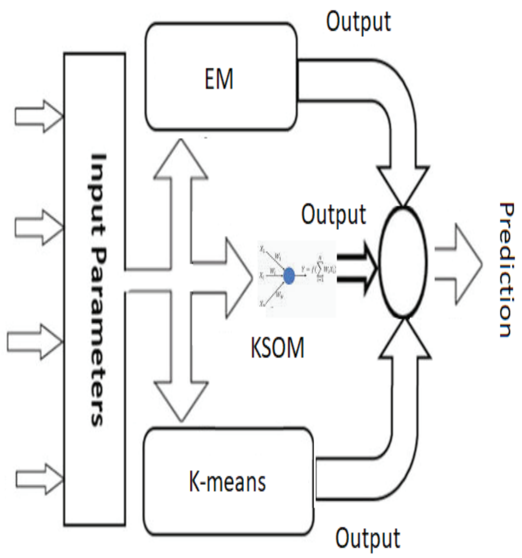


Figure 3

Schematic illustration of prediction using EM, KSOM and K-Means Algorithms.

RESULTS AND DISCUSSION

In this research, the dataset is first selected, then data mining techniques are utilized in finding the parameters. In general, eight parameters (cement, blast furnaces slag, fly ash, water, super plasticizer, coarse aggregate, fine aggregate and age) were examined against concrete compressive strength using three data mining algorithms. This section discusses, compares and evaluates these algorithms using concrete dataset to investigate the main factors that affect concrete mix strength.

Table 2 represents the primary results of EM algorithm. To get the result, different datasets were used with different numbers of clusters (K=3,5,7,and 9) as shown in Table 2.

For each number of clusters, we computed different statistical values. In our case, we used standard deviation as a statistical measure to select the main factors that affect the CCS. Table 2 summarizes our calculations and shows only the most influential factors on the CCS. For example, when K=5, we find that the following three factors blast furnaces slag, fly ash, and super plasticizer imapct the CCS.

The values show the different results of predicting the main factors that affect Concrete Compressive Strength (CCS) using EM algorithm based on eight components of concrete mix. These results are computed and visualized using WEKA Tool.

Figure 4 shows the relationship between the main components that affect the concrete mix and the parameter Concrete Compressive Strength (CCS) using EM Algorithm. As shown in these figures, the values of Concrete Compressive Strength (CCS) as a function computed based on Superplasticizer, Fly Ash and Blast Furnace Slag serve obtained high similarity values.

Table 2.

Screen dumps of the results of EM Algorithms Using WEKA

Number of Clusters	Results of EM
EM (with K= 3)	Superplasticizer mean std. dev.
EM (with K= 5)	Blast Furnace Slag mean 71.726 std. dev. 69.762 Fly Ash mean 8.6447 std. dev. 30.1856 Superplasticizer mean 0.34 std. dev. 1.18

Number of Clusters	Results of EM									
EM (with K= 7)	Blast Furnace Slag									
	mean	23.1165	140.6642	82.718	0	26.5337	192.7328	22.9621		
	std. dev.	23.3759	65.9588	73.0192	0.0002	51.3771	61.611	40.8663		
	Fly Ash									
	mean	110.9131	0.0035	0.0107	0	1.5761	0.4274	120.6712		
	std. dev.	26.8864	0.2928	1.0604	61.4471	8.8978	3.2074	32.6375		
	Superplasticizer									
	mean	10.2752	14.6176	0.0006	0	3.0277	0.5002	7.9891		
	std. dev.	3.8984	6.4238	0.0616	0.0004	5.3601	1.9652	2.9272		
EM (with K= 9)	Blast Furnace Slag									
	mean	4.0644	90.9507	82.6599	8.8915	175.5803	0.4714	21.0026	33.7256	182.1985
	std. dev.	13.4621	48.8117	72.6721	29.1616	78.743	2.3478	5.7829	44.2412	48.6432
	Fly Ash									
	mean		110.9131	0.0035	0.0107	0		1.5761	0.4274	120.6712
	std. dev.		26.8864	0.2928	1.0604	61.4471		8.8978	3.2074	32.6375
	Superplasticizer									
	mean	0.9103	17.5907	0.0002	0.5885	0.0253	7.479	10.4851	8.4821	11.8749
	std. dev.	2.3356	7.5873	0.036	1.8861	0.3856	3.3652	3.8487	2.4399	3.313

After designing EM model for predicting the main factors that affect concrete compressive strength and analyzing the results obtained by the EM algorithm, it is clear that the EM algorithm achieves the optimal mix of the concrete components.

After running the EM algorithm on the dataset for a number of times with varied values for number of clusters, the best parameters were selected based on their Standard deviation values. Table 3 shows the list of the main factors that affect Concrete Compressive Strength (CCS) with their standard deviations.

Figure. 4 illustrates the values of concrete compressive strength predicted by the EM algorithm versus the other components such as Superplasticizer, Fly Ash and Blast Furnace Slag, for both training and testing datasets. As shown in figure 4, there is a consistent indication among the different combinations of the three components and the concrete compressive strength. It is clear that the distribution of points in the three planes shows the same picture.

EM with 9 Clusters

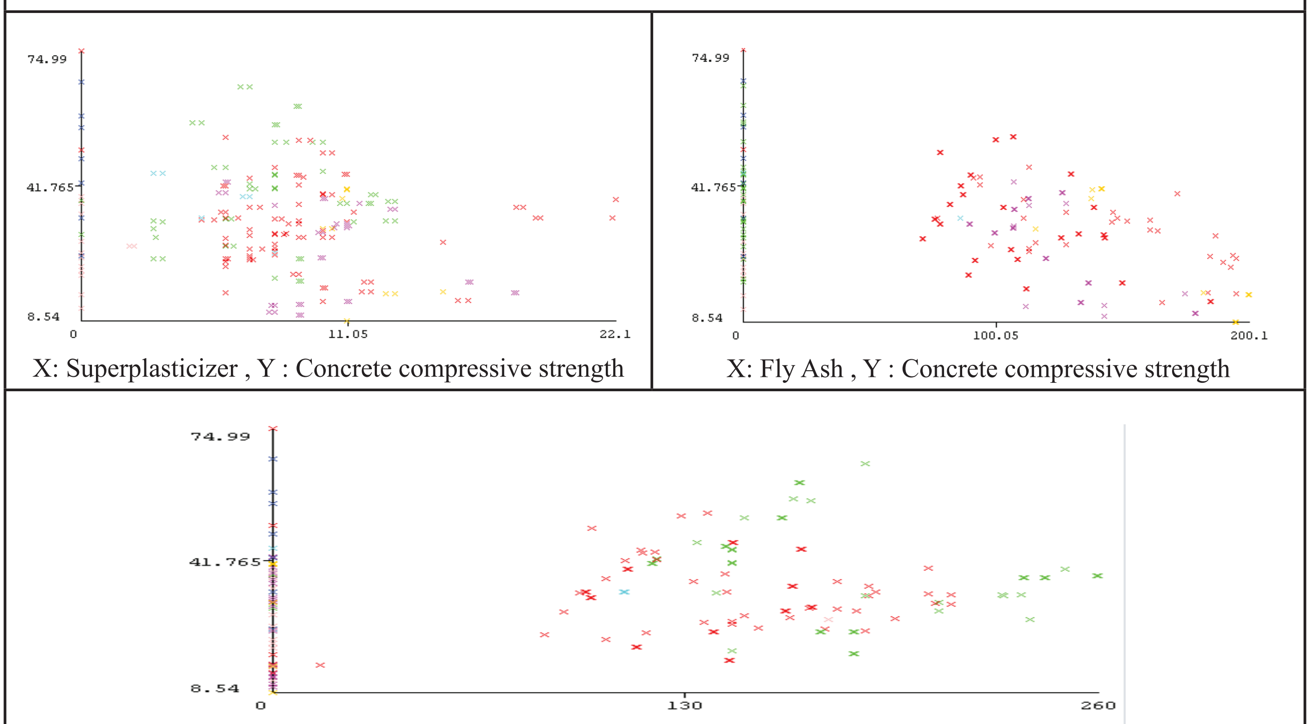


Figure 4.

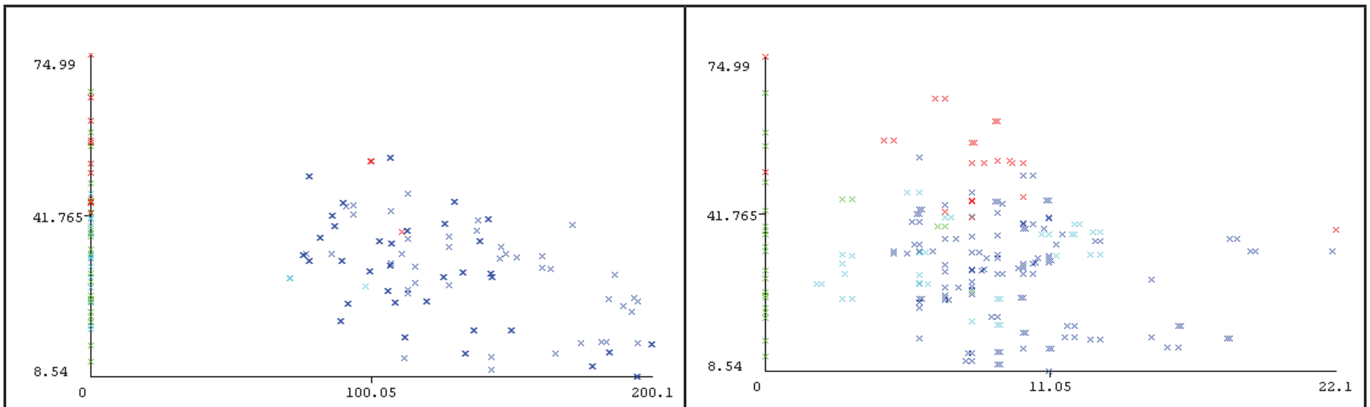
Plotting of the main components the affect the concrete using EM Algorithm

Table 3.

List of the main components that affect compressive strength of concrete (EM)

Number of Clusters	Standard. Deviation	Predict Components
3	0.0001	Superplasticizer
	0.015	Blast Furnace Slag
5	3.265	Fly Ash
	0.2488	Superplasticizer
	0.0004	Superplasticizer
7	0.2928	Fly Ash
	0.0002	Blast Furnace Slag
	0.0001	Superplasticizer
9	0.0148	Fly Ash
	2.3478	Blast Furnace Slag

The second model use the KSOM algorithm. This algorithm is employed to illustrate the components that affect concrete compressive strength. In the KSOM algorithm, the main components that affect the Concrete Compressive Strength (CCS) are Fly Ash and Superplasticizer. Figure 5 shows the results.

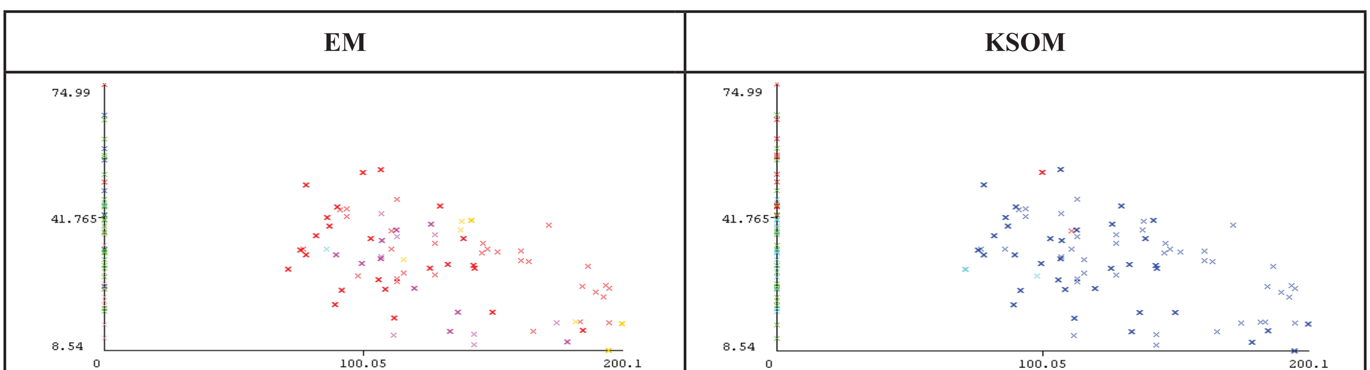


X: Fly Ash , Y : Concrete Compressive Strength | X: Superplasticizer, Y : Concrete Compressive Strength

Figure 5.

Fly Ash and Superplasticizer versus Concrete Compressive Strength (KSOM)

Figure 6 illustrates a comparison between the EM and KSOM algorithms. As the figure shows, the predicted models for the two components are highly similar. The performance of fly ash on concrete compressive strength has the same significant effect. The analysis of the two graphs shows that the two algorithms have the same effect among the potentially used two input parameters, fly ash and Superplasticizer.



X: Fly Ash , Y : Concrete Compressive Strength

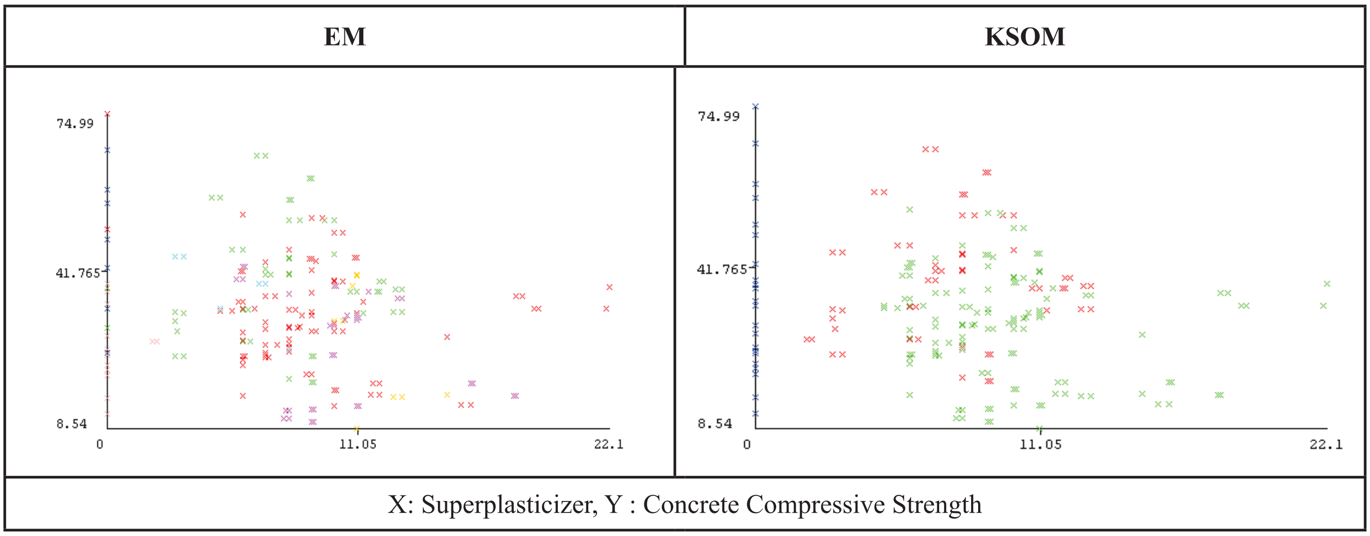


Figure 6.

Comparing EM and KSOM Algorithms

The K-means algorithm is applied to the datasets, using different value for k = 3,5,7 and 9. Table 4 shows the results of clustering with the different value for K= 3,5, 7 and 9.

Based on the analysis of the result of K-Means we find that the factors that mostly affect the compressive strength on concrete mix are Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate (Table 5). According to the results, Table 6 presents a summary of the key attributes that affect the concrete compressive strength using the three different algorithms.

Referring to the results in table 6, K-Means algorithm shows that Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate are the most common components that affect the Concrete Compressive Strength (CCS) mix. In EM and KSOM algorithms two common component are considered, Fly Ash and Superplasticizer. At the same time, EM algorithms includes a distinguished component which is the Blast Furnace Slag. It is clear that, all the three algorithms show intersection and provide different information. In general, the analysis concludes that Fly Ash and Superplasticizer are common components and they are the two main factors that affect concrete compressive strength.

Table 4.

Screen dumps of the Results For K-Means (with K= 3,5, 7 and 9)

Number of Clusters	Results For K-Means (with K= 3,5, 7 and 9)
K-Means (with K= 3)	(see dump below)

```
Final cluster centroids:
                                                  Cluster#
Attribute                        Full Data           0           1           2
                                   (806.0)     (360.0)     (295.0)     (151.0)
==============================================================================
Cement                            292.8646    284.8378    246.1525    403.2603
Blast Furnace Slag                 67.3143     83.2689     18.9129    123.8358
Fly Ash                            47.4553      0.9153    124.3339      8.2185
Water                             179.8442    197.2456    169.0492     159.447
Superplasticizer                    5.6511      0.2769      8.3688     13.1543
Coarse Aggregate                   985.786    992.7369   1001.0068    939.4781
Fine Aggregate                    778.3337    755.3672    805.9288    779.1775
Age                                49.5546     64.5111          37     38.4238
Concrete compressive strength      36.5954     28.7541     35.4996     57.4306
```

Number of Clusters	Results For K-Means (with K= 3,5, 7 and 9)

K-Means (with K= 5)

Attribute	Full Data (806.0)	Cluster# 0 (149.0)	1 (297.0)	2 (88.0)	3 (57.0)	4 (215.0)
Cement	292.8646	200.2141	247.4983	373.85	428.8509	350.5428
Blast Furnace Slag	67.3143	187.5711	18.9471	148.1057	95.4404	10.2628
Fly Ash	47.4553	1.3154	124.0286	13.142	0	0.2791
Water	179.8442	196.4242	169.0017	164.6159	150.293	197.3991
Superplasticizer	5.6511	0.594	8.3906	11.0352	17.4947	0.0279
Coarse Aggregate	985.786	974.1993	1000.7778	978.5557	868.3368	1007.2033
Fine Aggregate	778.3337	751.1007	805.2963	729.2545	875.9649	754.1656
Age	49.5546	45.3356	36.798	38.1705	35.0877	78.5953
Concrete compressive strength	36.5954	26.3142	35.5209	59.998	53.5979	31.1184

K-Means (with K= 7)

Final cluster centroids:

Attribute	Full Data (806.0)	Cluster# 0 (128.0)	1 (244.0)	2 (79.0)	3 (60.0)	4 (66.0)	5 (164.0)	6 (65.0)
Cement	292.8646	194.9336	215.3877	368.1253	431.1583	357.6136	329.2226	399.9446
Blast Furnace Slag	67.3143	192.768	18.7746	157.7367	96.6083	66.4136	4.4921	24.9585
Fly Ash	47.4553	0	125.3332	3.2278	0	0	1.0457	111.4031
Water	179.8442	195.3016	168.8914	165.0646	151.8333	217.4318	190.7787	168.5846
Superplasticizer	5.6511	0.2008	7.982	10.6076	17.065	0	0.3262	10.2477
Coarse Aggregate	985.786	970.3328	1020.9295	995.5886	867.525	958.9697	1022.5116	916.1108
Fine Aggregate	778.3337	758.6336	811.9779	722.6987	871.2417	660.6455	789.5463	763.8985
Age	49.5546	30.1406	39.5164	38.2278	36.25	213.5	33.1768	26.3692
Concrete compressive strength	36.5954	24.2441	33.5362	59.637	54.4978	45.3738	25.4502	47.0786

K-Means (with K= 9)

Final cluster centroids:

Attribute	Full Data (806.0)	Cluster# 0 (128.0)	1 (60.0)	2 (67.0)	3 (60.0)	4 (42.0)	5 (153.0)	6 (116.0)	7 (48.0)	8 (132.0)
Cement	292.8646	194.7477	405.5333	349.6239	431.1583	317.5524	312.0131	237.1379	473.0354	198.5303
Blast Furnace Slag	67.3143	191.7852	26.5383	188.6418	96.6083	83.2333	6.4098	2.7414	12.3229	32.5227
Fly Ash	47.4553	0	111.8	1.8284	0	0	1.6013	107.2853	2.4792	140.9803
Water	179.8442	195.8703	167.7	165.3836	151.8333	220.5714	190.4824	176.65	194	162.2659
Superplasticizer	5.6511	0.0461	10.6217	11.7821	17.065	0	0.4725	7.3328	1.0333	8.5288
Coarse Aggregate	985.786	970.4109	915.3833	979.5582	867.525	943.9619	1018.7843	985.4974	1031.3458	1048.3583
Fine Aggregate	778.3337	757.1438	761.7167	727.4851	871.2417	675.1048	802.7582	846.4509	647.5875	782.2326
Age	49.5546	31.0156	25.3333	37.4776	36.25	278.0952	36.7908	37.9397	55.1667	40.9621
Concrete compressive strength	36.5954	24.5193	47.63	58.2196	54.4978	44.5945	24.5222	30.9368	49.6467	35.8519

Table 5.

K-Means - factors that mostly affect the concrete compressive strength.

Number of Cluster	Components
3	Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate
5	Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate
7	Fly Ash, Coarse Aggregate and Fine Aggregate,
9	Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate

Table 6.

Summary of the main components that affect concrete mix using the three algorithms.

K-Means	EM	KSOM
Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate	Fly Ash, Superplasticizer and Blast Furnace Slag	Fly Ash and Superplasticizer

Table 7.

The relation between no. of Cluster, Sum of Squared Errors and Concrete Compressive Strength (CCS) using K-Means.

No. of Clusters	Sum Of Squared Errors (SSE)	Number Of Iterations	Concrete Compressive Strength (CCS) (Average Actual Data is 35.818)
3	286.5	18	56.2506
4	244.2	11	56.9138
5	219.1	18	56.448
6	205.8	10	56.8346

No. of Clusters	Sum Of Squared Errors (SSE)	Number Of Iterations	Concrete Compressive Strength (CCS) (Average Actual Data is 35.818)
7	182.6	30	57.042
8	176.1	12	57.2971
9	159.198	17	56.9463
12	138.4	22	54.764
15	122.486	26	53.4718
20	104.0	24	55.7447
25	94.18	16	56.8314
30	83.77	17	63.3709
50	62.3	16	67.23

Table 8 and figure 5 show the prediction of the Concrete Compressive Strength (CCS) by applying both K-Means and KSOM using WEKA. We find the actual average of Concrete Compressive Strength (CCS) is equal to 35.818. By comparing the results of the Concrete Compressive Strength CCS of both algorithms, we find a slight intersection or similarity between K-Means and KSOM algorithm.

Table 8.

Concrete Compressive Strength (CCS) Prediction K-Means vs. KSOM

No. of Clusters	Concrete Compressive Strength (CCS) Prediction (Average Actual Data is 35.818)	
	K-Means	KSOM
2	36.9804	34.8796
3	56.2506	55.2417
4	56.9138	56.9722
5	56.448	56.179
6	56.8346	56.88
8	57.2971	58.616
10	58.7342	58.9955
CCS Prediction Average	54.2084	53.9663

The values obtained using K-Means and KSOM in WEKA, indicate that the estimation results of CCS predication for both algorithms are very close. The results show that the K-Means can be successfully used to give a more accurate prediction for increasing the Concrete Compressive Strength (CCS) (54.2084) than the average actual data (35.818) and KSOM.

This study applied three algorithms and compared their results to find the main components that affect the Concrete Compressive Strength (CCS) using the WEKA tool. It was noted that the results of the EM algorithm is one of the most accurate and effective tools for finding the factors affecting the Concrete Compressive Strength. On the other hand, K-Means and KSOM algorithms are the most adequate algorithms for improving Concrete Compressive Strength mix.

Results of this study can be used to predict the main factors that affect the compressive strength of concrete and the mixtures of concrete.

Table 6 shows the main predicted components that affect the concrete compressive strength. These components are Blast Furnace Slag, Fly Ash, Superplasticizer, Coarse Aggregate and Fine

Aggregate. The analysis of the data in Table 8 and Table 9 show a significant correlation between the prediction of improving the CCS and the main factors that affect the CCS. The values for these parameters are similar among the three Data Mining algorithms. These results are very important because they provide us with the threshold values that improve the CCS. These parameters increased the performance of CSS from 35.818 to 58.9955. They were also able to increase the performance model from 36% to 59% of CCS.

Table 9.

Summary of the main components that improve the performance of concrete compressive strength.

Predictive parameters	K-Means	EM	KSOM	Average Value (kg/m3 mixture)	Mean
Blast Furnace Salg	-	0.4714		179.7	73.896
Fly Ash	0.0	0.0	0.0	100.05	54.188
Superplasticizer	0.0	0.0253	0.0355	16.1	6.205
Coarse Aggregate	867.525			973	972.91
Fine Aggregate	727.4851			793.3	773.58

Furthermore, these results reinforce the predication model through improving the CCS and reducing the cost of the concrete mixtures. For example, the cost of fly ash is varying and expressive. In our model, it is important to note that the cost of fly ash is beyond concrete mixture because the three Data Mining algorithms suggest a threshold value of zero for fly ash.

Overall, applying the different algorithms of Data Mining to our datasets proved to be very effective in predicting and improving the concrete compressive strength.

While all input parameters are very important and effective in predicting concrete compressive strength based on the laboratory test, our analysis shows that there are more effective parameters in our input that improve the performance of concrete compressive strength.

Our analysis shows that the performance of each Data Mining algorithm is similar yet with a small difference between them. Moreover, each one of them is appropriate for the prediction for improving CCS.

CONCLUSION

The main aim of this present study is to find the key components that affect Concrete Compressive Strength (CCS). To accomplish this research, the datasets were selected, then three data mining algorithms (EM, KSOM and K-Means) were applied. The actual input parameters consists of eight parameters and one output CCS. The input parameters were examined against CCS using the three data mining algorithms. The results were analyzed and discussed. The study used WEKA as a tool for data mining techniques.

This study focuses on including all the different components of the concrete in our prediction model and in finding the main factors that influence the high performance of concrete to increase the Concrete Compressive Strength (CCS) mix, using three different algorithms.

Results showed that using data mining techniques is highly effective in predicting the main factors that affect CCS. The analysis shows that K-Means and KSOM algorithms are the most accurate algorithm to predict the CCS. At the same time, EM is useful for predicting the main factors that affect the CCS.

In general, data mining techniques are very effective tools in predicting concrete compressive strength as well as the main factors that affect and improve the performance of concrete compressive strength. Our study can be expanded to include additional parameters, such as humidity, moisture, temperature, and methods of mixing etc. These parameters might be able to improve the prediction of CCS.

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Contents

Hyers-Ulam-Rassias Stability of the Inhomogeneous Wave Equation

استقرار حلّ المعادلة الموجية غير المتجانسة بمفهوم هيريس ـ أولام ـ راسيس

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Abstract:

In this paper, we apply the Duhamel's Principle to prove the Hyers-Ulam-Rassias stability for one-dimensional inhomogeneous wave equation on an infinite homogeneous string with zero initial conditions. We have also established the Hyers-Ulam-Rassias stability of nonzero initial value problem of the inhomogeneous wave equation for an infinite string. Some illustrative examples are given.

Keywords: Hyers-Ulam-Rassias Sability, Wave Equation, Duhamel's Principle.

ملخص:

في هذا البحث، استخدم الباحث مبدأ ديوهامل لإثبات استقرار بمعنى هيريس–أولام–راسيس لحلّ المعادلة الموجية غير المتجانسة عبر وتر متجانس ولا نهائي، عندما تكون الشروط الابتدائية صفرية. ولقد أثبت أيضًا الاستقرار للمعادلة الموجية غير المتجانسة عبر وتر متجانس ولا نهائي، عندما تكون الشروط الابتدائية غير صفرية. وجرى دعم النتائج ببعض الأمثلة التوضيحية.

الكلمات المفتاحية: الاستقرار بمفهوم هيريس–أولام–راسيس، المعادلة الموجية، مبدأ ديوهامل.

1- Introduction and Preliminaries

The study of stability problems for various functional equations originated from a famous talk given by Ulam in 1940. In the talk, Ulam discussed a problem concerning the stability of homomorphisms. A significant breakthrough came in 1941, when Hyers [1] gave a partial solution to Ulam's problem. After that and during the last two decades, a great number of papers have been extensively published concerning the various generalizations of Hyers result .(see [2-10]).

Alsina and Ger [11] were the first mathematicians who investigated the Hyers-Ulam stability of the differential equation $g' = g$. They proved that if a differentiable function $y : I \to R$ satisfies $|y' - y| \le \varepsilon,\ \varepsilon > 0,$ for all $t \in I,$ then there exists a differentiable function $g : I \to R$ satisfying $g'(t) = g(t)$ for any $t \in I$ such that $|g - y| \le 3\varepsilon,$ for all $t \in I.$ This result of Alsina and Ger has been generalized by Takahasi et al [12] to the case of the complex Banach space valued differential equation $y' = \lambda y.$

Furthermore, the results of Hyers-Ulam stability of differential equations of first order were also generalized by Miura et al. [13], Jung [14] and Wang et al. [15].

Gordji et al. [16] generalized Jung's result to first order and second order nonlinear partial differential equations. Lungu and Craciun [17] established results on the Ulam-Hyers stability and the generalized Ulam-Hyers-Rassias stability of nonlinear hyperbolic partial differential equations. Jung [18], Choi and Jung [19] had used coordination substitution way and respectively, the method of a kind of dilation invariance to prove the generalized Hyers-Ulam stability of wave equation. E. Biçer [20] applied Laplace transform technique to establish the Hyers-Ulam stability for the wave equation.

In this paper we consider the Hyers-Ulam-Rassias stability of the nonhomogeneous

wave equation

$$\frac{\partial^2 u}{\partial t^2} = a^2 \frac{\partial^2 u}{\partial x^2} + g(x,t) \quad 0 < t < \infty, \quad -\infty < x < \infty, \tag{1.1}$$

with zero initial condition

$$u(x,0) = 0, \ \ u_t(x,0) = 0, \tag{1.2}$$

where $u(x,t) \in C^2[\mathbb{R} \times (0,\infty)].$

Moreover we have proved sufficient conditions for Hyers-Ulam-Rassias stability of the inhomogeneous wave equation

$$\frac{\partial^2 u}{\partial t^2} = a^2 \frac{\partial^2 u}{\partial x^2} + g(x,t), \quad 0 < t < \infty, \quad -\infty < x < \infty \tag{1.3}$$

with nonzero initial condition

$$u(x,0)=\alpha(x),\ u_t(x,0)=\beta(x),\ -\infty<x<\infty \qquad (1.4)$$

where $u(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$, $\alpha(x)\in C^2(\mathbb{R}^1)$, and $\beta(x)\in C^1(\mathbb{R}^1)$.

Definition 1 [21] We will say that the equation (1.1) has the Hyers-Ulam-Rassias (HUR) stability if there exists $K>0$, $\varphi(x,t):\mathbb{R}\times\mathbb{R}\to\mathbb{R}$ and for each solution $u(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the inequality

$$|\ u_{tt}-a^2u_{xx}-g(x,t)\ |\le\varphi(x,t)$$

with the initial condition (1.2) then there exists a solution $w(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the equation (1.1) such that $|\ u(x,t)-u_0(x,t)\ |\le K\varphi(x,t)$, $\forall(x,t)\in\mathbb{R}\times(0,\infty)$, where K is a constant that does not depend on φ nor on $u(x,t)$, and $\varphi(x,t)\in C(\mathbb{R}\times(0,\infty))$.

Definition 2 [21] We will say that the equation (1.3) has the Hyers-Ulam-Rassias (HUR) stability with respect to $\varphi>0$, if there exists $K>0$ such that for each $\varepsilon>0$ and for each solution $u(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the inequality

$$|\ u_{tt}-a^2u_{xx}-g(x,t)\ |\quad\le\varphi(x,t)$$

with the initial condition (1.4) then there exists a solution $w(x,t)\in C^2(\mathbb{R}\times(0,\infty))$ of the equation (1.3) such that $|\ u(x,t)-u_0(x,t)\ |\le K\phi(x,t)$, $\forall(x,t)\in\mathbb{R}\times(0,\infty)$, where K is a constant that does not depend on φ nor on $u(x,t)$, and $\phi(x,t)\in C(\mathbb{R}\times(0,\infty))$.

Now, to motivate the Duhamel method for stability of the infinite homogeneous string in the sense of Hyers-Ulam-Rassias we will consider the following related problem

$$\frac{\partial^2 v}{\partial t^2}=a^2\frac{\partial^2 v}{\partial x^2},\quad t>s,\ -\infty<x<\infty \qquad (1.5)$$

with initial condition

$$v(x,s;s)=0,\ v_t(x,s;s)=g(x,s) \qquad (1.6)$$

where $v(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$.

Now, notice that the problem (1.5),(1.6) has initial conditions prescribed at arbitrary time $t=s$, rather than at $t=0$. Thus we can rewrite $v(x,t;s)=w(x,t-s;s)$ where $w(x,t-s;s)$ solves the problem

$$\frac{\partial^2 w}{\partial t^2}=a^2\frac{\partial^2 w}{\partial x^2},\quad t>s,\ -\infty<x<\infty \qquad (1.7)$$

with initial condition

$$w(x,0;s)=0,\ w_t(x,0;s)=\ g(x,s) \qquad (1.8)$$

where $w(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$.

(Duhamel's Principle for the wave equation (1.1), see [22]) If $g(x,t)\in C^1(\mathbb{R})$ in x and $C^0(0,\infty)$ in t, then

$$u(x,t)=\int_0^t v(x,t;s)ds=\int_0^t w(x,t-s;s)ds$$

$$=\frac{1}{2a}\int_0^t\int_{x-a(t-s)}^{x+a(t-s)} g(r,s)drds \qquad (1.9)$$

2. On Hyers-Ulam-Rassias Stability for Inhomogeneous Wave Equation

First consider the HUR stability of the IV problem (1.3),(1.4) of forced vibrations of a homogeneous infinite string with zero initial conditions.

Theorem1.1 If $v(x,t.;s)\in C^2[\mathbb{R}\times(0,\infty)]$, solves the homogeneous problem (1.7),(1.8), $u(x,t)\in C^2[\mathbb{R}\times(0,\infty)]$ and there is a function $\varphi(x,t):\ \mathbb{R}\times\mathbb{R}\to\mathbb{R}^+$, such that

$$\int_0^t\int_0^s\varphi(x,y)dyds\le K\varphi(x,t) \qquad (2.1)$$

then the IV inhomogeneous problem (1.1),(1.2) is stable in the sense of HUR.

Proof. Let $\varphi(x,t) > 0$ and $u(x,t)$ be an approximate solution of the IV problem (1.1),(1.2)

We will show that there exists a function $u_0(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ satisfying the equation (1.1) and the initial condition (1.2) such that

$$| u(x,t) - u_0(x,t) | \leq K\varphi(x,t)$$

For (1.1) let consider the inequality

$$-\varphi(x,t) \leq \frac{\partial^2 u}{\partial t^2} - a^2 \frac{\partial^2 u}{\partial x^2} - g(x,t) \quad \leq \varphi(x,t) \tag{2.2}$$

Since $u(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$, we integrate (2.2) with respect to t, to obtain

$$-\int_0^t \varphi(x,s)ds \leq u_t(x,t) - u_t(x,0) - \int_0^t g(x,s)ds - a^2 \int_0^t u_{xx}(x,s)ds$$
$$\leq \int_0^t \varphi(x,s)ds \tag{2.3}$$

By virtue of (1.9) and the initial condition (1.8), we have

$$-\int_0^t \varphi(x,s)ds \leq u_t(x,t) - \int_0^t w_t(x,0,s)ds - a^2 \int_0^t \int_0^s w_{xx}(x,t-s,s)ds$$
$$\leq \int_0^t \varphi(x,s)ds$$

Or, equivalently

$$-\int_0^t \varphi(x,s)ds < u_t(x,t) - \int_0^t w_t(x,0;s)ds - \int_0^t \int_0^s w_{tt}(x,t-s;s)ds$$
$$\leq \int_0^t \varphi(x,s)ds \tag{2.4}$$

Since

$$\frac{\partial}{\partial t} \int_0^t \int_0^s w_t(x,t-s;y)dyds = \int_0^t w_t(x,0;s)ds + \int_0^t w_{tt}(x,t-s;s)ds \tag{2.5}$$

Then by integrating the inequality (2.4) and using (2.1) we get

$$-C\varphi(x,t) < -\int_0^t \int_0^s \varphi(x,y)dyds \quad < u(x,t) - u(x,0) - \int_0^t \int_0^s u_t(x,t-s;y)dyds$$
$$\leq \int_0^t \int_0^s \varphi(x,y)dyds \leq C\varphi(x,t),$$

Use the initial conditions (1.2),(1.8) to obtain

$$-C\varphi(x,t) \leq u(x,t) - \int_0^t w(x,t-s;s)ds \leq C\varphi(x,t), \tag{2.6}$$

Now, we show that

$$u_0(x,t) = \int_0^t w(x,t-s;s)ds \tag{2.7}$$

satisfies the problem (1.1),(1.2). Indeed Since $w(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$, we differentiate twice, successively with respect to t in order to obtain

$$\frac{\partial}{\partial t} u_0(x,t) = w(x,0;s) + \int_0^t w_t(x,t-s;s)ds = \int_0^t w_t(x,t-s;s)ds \tag{2.8}$$

and

$$\frac{\partial u_{tt}(x,t)}{\partial t} = w_t(x,0;t) + \int_0^t w_{tt}(x,t-s;s)ds$$
$$= g(x,t) + a^2 u_{xx}(x,t),$$

this shows that $u(x,t)$ is a solution of (1.1). The equations (2.7),(2.8) yield $u_0(x,0) = 0$ and $u_t(x,0) = 0$, respectively

By D'Alembert formula, the solution of the problem (1.7), (1.8) is given by

$$w(x,t) = \frac{1}{2a} \int_{x-at}^{x+at} g(r,s)ds \tag{2.10}$$

Hence

$$u_0(x,t) = \int_0^t w(x,t-s;s)ds = \frac{1}{2a} \int_0^t \int_{x-a(t-s)}^{x+a(t-s)} g(r,s)drds \tag{2.11}$$

From (2.6) and (2.7) we infer that the IV problem (1.1), (1.2) is stable in the sense of HUR.

To illustrate the obtained results we give the following example.

Example 2.1 Let the following IV problem be given

$$u_{tt} - u_{xx} = 0 \qquad (2.12)$$

$$u(x,0) = 0,\ u_t(x,0) = 0 \qquad (2.13)$$

To establish the HUR stability let consider the inequality

$$-\varphi(x,t) \le u_{tt} - u_{xx} - x + t \le \varphi(x,t) \qquad (2.14)$$

Integrating (2.14) successively twice with respect to t, the last inequality yield

$$-C\varphi(x,t) \le u(x,t) - \int_0^t \int_0^s w_f(x,t-y;y)\,dy\,ds \le C\varphi(x,t), \qquad (2.15)$$

or

$$-C\varphi(x,t) \le u(x,t) - \int_0^t \int_0^s (x-y)\,dy\,ds \le C\varphi(x,t), \qquad (2.16)$$

One can show that

$$u_0(x,t) = \int_0^t \int_0^s (x-y)\,dy\,ds = \frac{1}{2}t^2 x - \frac{1}{6}t^3 \qquad (2.17)$$

is a solution of (2.12),(2.13).

Now if we let

$$\varphi(x,t) = e^{x+t}, \qquad (2.18)$$

then from (2.16) and (2.18), we get

$$-C\int_0^t \int_0^s e^{x+t}\,dy\,dt \le u(x,t) - \int_0^t \int_0^s (x-y)\,dy\,ds \le C\int_0^t \int_0^s e^{x+t}\,dy\,dt \qquad (2.19)$$

Or, equivalently letting $C = 1$ and putting the result

$$\int_0^t \int_0^s e^{(x+s)}\,dy\,dt = e^x\left(e^t - t - 1\right) \le e^{x+t},\ \forall t \in (0,\infty)$$

in (2.19), we have

$$-e^{x+t} \le u(x,t) - \frac{1}{2}t^2 x - \frac{1}{6}t^3 \le e^{x+t} \qquad (2.20)$$

Hence, the IV problem (2.12), (2.13) is stable in the sense of HUR.

Now we will consider the HUR stability of the IV problem (1.1), (1.2) of forced Vibrations of a homogeneous infinite string with nonzero initial conditions. For this purpose, we consider the following related problems for stability of the infinite homogeneous string in the sense of HUR.

$$\frac{\partial^2 v}{\partial t^2} = a^2 \frac{\partial^2 v}{\partial x^2},\quad t > s,\ -\infty < x < \infty \qquad (2.21)$$

with initial condition

$$v(x,s;s) = 0,\ v_t(x,s;s) = g(x,s) \qquad (2.22)$$

where $v(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$.

Now, notice that the problem (2.21),(2.22) has initial conditions given at arbitrary time $t = s$, instead of at $t = 0$. Thus we can rewrite $v(x,t;s) = w(x,t-s;s)$ where $w(x,t-s;s)$ solves the problem

$$\frac{\partial^2 w}{\partial t^2} = a^2 \frac{\partial^2 w}{\partial x^2},\quad t > s,\ -\infty < x < \infty \qquad (2.23)$$

with initial condition

$$w(x,0;s) = 0,\ w_t(x,0;s) = g(x,s) \qquad (2.24)$$

where $w(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$. Now, let $\mu(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ be a solution of IV Problem

$$\frac{\partial^2 \mu}{\partial t^2} = a^2 \frac{\partial^2 \mu}{\partial x^2},\quad t > s,\ -\infty < x < \infty \qquad (2.25)$$

with initial condition

$$\mu(x,0;s) = \alpha(x),\ \mu_t(x,0;s) = \beta(x) \qquad (2.26)$$

If $v(x,t;s) \in C^2[\mathbb{R} \times (0,\infty)]$, solves the homogeneous problem (2.25),(2.26) and $\varphi(x,t) : \mathbb{R} \times \mathbb{R} \to \mathbb{R}^+$, such that

$$\int_0^t \int_0^s \varphi(x,y)\,dy\,ds \le K\varphi(x,t)$$

then the IV inhomogeneous problem (1.3),(1.4) is stable in the sense of HUR.

Proof. Let $\varphi(x,t) > 0$ and $u(x,t)$ be an approximate solution of the IV problem (1.3),(1.4). We will show that there exists a function $u_0(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ satisfying the equation (1.3) and the initial condition (1.4) such that

$$| u(x,t) - u_0(x,t) | \le K\varphi(x,t)$$

First we make a substitution $u(x,t) = \mu(x,t) + w(x,t)$, where $\mu(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$ is a solution of IVP (2.25),(2.26).

Consider the following inequality associated with Eq. (1.3)

$$-\varphi(x,t) \le \frac{\partial^2 u}{\partial t^2} - a^2\frac{\partial^2 u}{\partial x^2} - g(x,t) \le \varphi(x,t) \qquad (2.27)$$

By integration (2.27) with respect to t, we have

$$-\int_0^t \varphi(x,s)ds \le u_t(x,t) - u_t(x,0) - \int_0^t g(x,t)ds - a^2\int_0^t u_{xx}(x,t)ds$$

$$\le \int_0^t \varphi(x,s)ds \qquad (2.28)$$

By using (2.28) and the substitution

$$u(x,t) = \mu(x,t) + w(x,t), \qquad (2.29)$$

we obtain

$$-\int_0^t \varphi(x,s)ds \le u_t(x,t) - \mu_t(x,0) - \int_0^t w_t(x,0;s)ds - \int_0^t \mu_t(x,s)ds$$

$$-\int_0^t\int_0^s w_{tt}(x,t-y;y)dyds \le \int_0^t \varphi(x,s)ds \qquad (2.30)$$

Now, in view of the following

$$\frac{\partial}{dt}\left[\int_0^t \mu_t(x,s)ds + \int_0^t\int_0^s w_t(x,t-s;y)dyds\right]$$

$$= \mu_t(x,0;s) + \int_0^t \mu_t(x,s)ds + \int_0^t w_t(x,0;s)ds + \int_0^t\int_0^s w_{tt}(x,t-s;s)ds$$

we get

$$-C\varphi(x,t) \le -\int_0^t\int_0^s \varphi(x,y)dyds \le u(x,t) - u(x,0) - \int_0^t \mu_t(x,s)ds$$

$$-\int_0^t\int_0^s w_t(x,t-y;y)dyds \le \int_0^t\int_0^s \varphi(x,y)dyds \le C\varphi(x,t)$$

Using (2.30) and (2.29) it follows that

$$-C\varphi(x,t) \le u(x,t) - \mu(x,0;s) - w_t(x,0;s) - \int_0^t \mu_t(x,s)ds$$

$$-\int_0^t\int_0^s w_t(x,t-s;s)dsdt \le C\varphi(x,t),$$

Now, we show that

$$u_0(x,t) = \int_0^t \mu_t(x,s)ds + \int_0^t w(x,t-s;s)ds =$$

$$= \mu(x,t) + \int_0^t w(x,t-s;s)ds \qquad (2.31)$$

satisfies the problem(1.3),(1.4). Indeed Since $u_0(x,t) \in C^2[\mathbb{R} \times (0,\infty)]$, we differentiate twice (2.31), successively with respect to t to obtain

$$\frac{\partial}{\partial t}\left[\int_0^t w(x,t-s;s)ds + \mu(x,t)\right] = w(x,0;t) + \int_0^t w_t(x,t-s;s)ds + \mu_t(x,t)$$

$$= \int_0^t w_t(x,t-s;s)ds + \mu_t(x,t) \qquad (2.32)$$

and

$$\frac{\partial^2}{\partial t^2}\left[w(x,0;t) + \int_0^t w_t(x,t-s;s)ds + \mu_t(x,t)\right]$$

$$= w_t(x,0;t) + \int_0^t w_{tt}(x,t-s;s)ds + \mu_{tt}(x,t)$$

$$= g(x,t) + w_{tt}(x,t) + \mu_{tt}(x,t) = g(x,t) + a^2 u_{xx}$$

This shows that $u_0(x,t)$ is a solution of (1.3). From (2.32) and the initial condition (2.26) it follows that $u_0(x,0) = \alpha(x)$ and $u_t(x,0) = \beta(x)$, respectively.

By virtue of (2.31) and applying D' Alembert formula to (2.25) and (2.26), the solution of equation (1.3) is given by

$$u_0(x,t) = \frac{1}{2}[\alpha(x+at) + \beta(x-at)] + \frac{1}{2a}\int_{x-at}^{x+at}\beta(s)ds$$

$$+\frac{1}{2a}\int_0^t\int_{x-a(t-s)}^{x+a(t-s)} g(r,s)drds \qquad (2.33)$$

Therefore, the solution (2.33) of the IV problem (1.3),(1.4) is stable in the sense of HUR.

Example 2.2 Let be given

$$u_{tt} - u_{xx} = x - t \qquad (2.34)$$

$$u(x,0) = x,\ u_t(x,0) = 1 - 2x \qquad (2.35)$$

Applying the same argument used in Theorems 2.1,2.3 we obtain

$$u_0(x,t) = \int_0^t w(x,t-s;s)ds + \mu(x,s)$$

where

$$\int_0^t w(x,t-s;s)ds = \int_0^t\int_0^s (x-y)dyds = \frac{1}{2}t^2x - \frac{1}{6}t^3$$

is the solution equation (2.34) with corresponding zero initial conditions

$$u(x,0) = 0,\ u_t(x,0) = 0$$

and

$$\mu(x,t) = x + (1-2x)t$$

is a solution of IV Problem

$$\frac{\partial^2\mu}{\partial t^2} = a^2\frac{\partial^2\mu}{\partial x^2},\ t > s, \quad \infty < x < \infty$$

with initial condition

$$\mu(x,0;s) = x,\ \mu_t(x,0;s) = 1 - 2x$$

Then by (2.30), we have the solution of IV Problem (2.34),(2.35)

$$u_0(x,t) = x + (1-2x)t + \frac{1}{2}t^2x - \frac{1}{6}t^3$$

One can easily verify that initial condition(2.39) satisfies.

Now let $\varphi(x,t) = e^{x+t}$, then from (2.16),with $C = 1$, we get

$$-e^{x+t} \le -\int_0^t\int_0^x e^{x+t}dydt \le u(x,t) - x - (1-2x)t - \frac{1}{2}t^2x + \frac{1}{6}t^3$$

$$\le \int_0^t\int_0^x e^{x+t}dydt \le e^{x+t} \qquad (2.36)$$

By differentiating the inequality (2.36) twice with respect to t, we find

$$-e^{x+t} \le u_{tt}(x,t) - (x-t) \le e^{x+t} \qquad (2.37)$$

Therefore, the inequalities (2.36),(2.37) that the IV problem (2.34),(2.35) is stable in the

Therefore, the inequalities (2.36), (2.37) that the IV problem (2.34),(2.35) are stable in the sense of HUR.

Remark It should be noted here that it follows easily that the solutions (2.11), (2.33) are unique.

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An Efficient Anchor Nodes Distribution for Accurate Localization (EDAL) in Mobile Wireless Sensor Networks

توزيع نقاط الربط (المرساة) في شبكات الاستشعار اللاسلكية المتنقلة من أجل توطين دقيق (EDAL)

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Abstract:

The velocity parameter in mobile Wireless Sensor Networks (WSNs) is a critical factor in anchor nodes distribution. However, most of the previous schemes use the random velocity to transmit anchor nodes as in the waypoint mobility model, which produces a considerable overlap between anchor nodes without improving the localization accuracy. In this paper, we improve such model by controlling the anchor node velocity. In the proposed scheme (EDAL), the anchor node velocity is a function of the overlap degree between anchor nodes and number of anchor node in the neighbor. Thus, EDAL can distribute the anchor nodes efficiently to improve the localization accuracy and expand the coverage area simultaneously. We evaluate the EDAL performance through extensive simulation experiments.

Keywords: Wireless Sensor Networks, Waypoint Model.

ملخص:

تعد معلمة السرعة في شبكات الاستشعار اللاسلكية المتنقلة (WSNs) عاملاً هامًا في توزيع نقاط الربط (المرساة)، معظم المخططات السابقة تستخدم السرعة العشوائية لإرسال نقاط الربط كما هو الحال في نموذج التنقل بنقطة الطريق (Waypoint)، والذي ينتج تداخلاً كبيرًا بين عقد الربط دون تحسين دقة التعريب. في هذه الورقة، نقوم بتحسين هذا النموذج من خلال التحكم في سرعة عقد الربط، في المخطط المقترح (EDAL)، تعد سرعة عقد الربط مهمة لحساب درجة التداخل بين عقد الربط وعدد العقد في الجوار، وبالتالي، يمكن لـ(EDAL)توزيع نقاط الربط بكفاءة لتحسين دقة التموضع وتوسيع مساحة التغطية في وقت واحد. نقيم أداء(EDAL)من خلال تجار بمحاكاة واسعة النطاق.

الكلمات المفتاحية: شبكات الاستشعار اللاسلكية المتنقلة، نموذج التنقل بنقطة الطريق.

1. Introduction

Mobile Wireless Sensor Networks (WSNs) consist of a large collection of small and low-cost devices [1]. These devices can communicate and collaborate with each other to collect and broadcast data. Mobile WSNs have been used in various applications, such as in disaster monitoring, tracking animals in wildlife sanctuaries, creates automatic mapping[2] and monitoring patients in hospital[3]. In tracking and monitoring applications[4-6], the location information of the collected data is crucial in estimating the precise location of the data origins[7].

In the literature, localization schemes of mobile WSNs can be classified into two categories, namely range-based and range-free[8]. The range-based category operates additional hardware, such as an array of antennas and acoustic devices to localize the sensor node [9],whereas the range-free scheme estimates the location of blind node (a node without location) via the network connectivity information without additional hardware.

In the range-free schemes, the anchor nodes broadcast its location information to aid in estimation of blind node location. However, the distribution of anchor nodes (a node with location information using GPS) over the operation area is highly affecting the network connectivity, coverage area and localization accuracy. Thus, it is important to design an efficient anchor node distribution method that able to expand anchor nodes throughout the coverage area which would lead to a better localization accuracy. The blind node requires at least three anchor nodes in the neighbor to estimate its location [10].

Most range-free localization schemes utilized the random waypoint mobility model to transmit the sensor node. Though the waypoint model has the advantage of being simple, it produces a large overlap between anchor nodes. The large overlap shows that the waypoint model is not efficient in distributing the anchor node since additional anchor nodes were used to cover an area even though they are not needed. This would consume more energy, requires more devices (e.g. GPS) and increase the overall cost of the whole implementation. An efficient node distribution for accurate localization should be able to maximize the coverage area by utilizing the available anchor node. This can be achieved by reducing the overlapping between the anchor nodes.

In this study, we develop a localization scheme to solve such problems by selecting the anchor node velocity as function of the overlap degree between anchor nodes and number of anchor nodes in the neighbor. The simulation results show that the proposed scheme can distribute anchor nodes efficiently, expand the anchor nodes coverage to 50% and improve the localization accuracy at the same time.

The rest of this manuscript is organized as follows: Section 2 presents the related work in localization scheme and mobility model. Section 3 explains the methodology of the EDAL scheme. The experimental protocol and its parameters are described and their results are presented in Section 4. Finally, Section 5 concludes the paper and outlines the future work.

2. Related Work

Compared to a static network, mobile WSNs have a higher coverage area with a limited number of sensor nodes. However, the mobility property of mobile sensors open a new challenge in estimating the location of blind node in WSNs. In this section, the related work is described in two sub-sections: localization scheme and mobility model.

2.1 Localization scheme

Localization schemes of mobile WSNs are categorized as range-based and range-free. The range-based scheme uses additional hardware to calculate the absolute distance between nodes. The deployment of additional hardware in WSNs is limited because of the restrictions in energy, size, cost and limited memory. Examples of hardware and their available methods are antenna which uses AoA[11], acoustic devices which measures the difference between light or sound signals via TDoA[12], and time synchronization between nodes in ToA. Another method in range-based scheme is received signal strength indicator (RSSI)that utilizes the relationship between signal strength and distance of the sensors. The localization accuracy of RSSI technology is affected by signal noise and weather conditions[13].

Range-free scheme estimates the location of blind nodes via network connectivity without additional hardware. In these schemes, three anchor nodes in the neighbor are required to estimate the blind node location in 2D space[10]. This estimation is based on the location information of the anchor nodes that broadcasted to the first and second hop neighbors in every time slot. Given the minimum dependency on anchor nodes, the range-free scheme is appropriate for indoor applications.

Location estimation of the mobile sensor node is a challenging task because the movement of mobile WSNs over time slot, in which affecting the localization accuracy. This challenge becomes more complicated for indoor localization applications since traditional solution such as GPS is highly affected by roofs, walls and other obstructions[14,15]. Additionally, the deployment of GPS in a sensor node is power-consuming and increases the costs and size of the sensor. Therefore, various localization schemes have been proposed to advance the location estimation of the mobile sensor in an indoor environment.

Mobile WSNs mainly use the SMC (Sequential Monte Carlo) technique to estimate the location of blind nodes in range-free schemes[16]. The SMC evaluates the posterior distribution function of the sample in the previous time slot to estimate the blind node location in current time. In each time slot, the normal node (node with location information in previous time slot) generates a new sample based on the sample from the previous time slot bounded by the maximum velocity (max-v). Anchor node constraints are then used to filter out the invalid samples. The processes are repeated until sufficient valid samples are generated. The average of weighted samples is later used for location estimation.

The Monte Carlo Localization (MCL) scheme[17] uses SMC technology to estimate the location of a blind node. Among the well-known techniques in WSNs localization which applies the SMC are MCL, MSL*, MCB and WMCL. In MCL, the location estimation of mobile sensor is simplified based on the following assumptions. First, the time is divided in an equal time slot, and second, the velocity of the sensor is limited to max-v. Moreover, the MCL estimates the location in three steps: initial, sample, and filter. The initial step involves the blind node generating samples randomly from the network bounded if it exists. This step is followed by the sample step, in which a new sample of the blind node is generated within a circle with a radius of max-v and is centered inside the area of previous time slot samples. In the filter step, anchor constraint is used to eliminate the weak samples and preserve the high weight samples. The anchor nodes constraints can be near or far and the near constraint is a region that is limited to radius R, whereas the far constraint is a region with a radius of R and 2R. The sample and filter steps should be repeated until sufficient valid samples are generated. The location estimation of the blind node is then calculated by averaging all valid samples.

In [18], MSL* was proposed to improve the localization accuracy of MCL. This technique uses the anchor and normal nodes location information in first and second hops. In each time slot, an anchor node and normal node broadcast their samples and sample weights to aid blind node location estimation. The sample weights of the anchor node are consistently high (one) and the normal node has a partial weight from zero to one. The weight of the normal node samples is calculated based on the distance between the samples of a normal node and the samples of another normal node in the neighbor. The use of normal nodes increases the localization accuracy substantially, but simultaneously increases the communication cost in WSNs. However, the communication cost is increased excessively in MSL* without improving the location accuracy. The communication cost of the MSL* is further improved in our previous research LCC [19] which emphasis on the selection of the closed normal nodes to the blind node based on the number of elements intersected between neighbors. This approach minimizes the communication cost while maintaining the localization accuracy as in MSL*. Nevertheless, the localization accuracy of MSL* decreases as the speed of the node increases. Thus, MSL* is more suitable for low-speed movement and static networks.

The MCB[20] scheme generates the sample from the bounded box method. The bounded box area is an intersection box between squares constructed by each anchor node over its center. This box minimizes the sample area and repetition in sample and filter steps. Thus, MCB scheme successfully improved the sampling efficiency but attained the same localization accuracy as in MCL. This is due to the fact that MCB used the same filtration strategy as in the MCL.

The sampling efficiency and localization accuracy of MCB are further improved in the Weighted Monte Carlo Localization scheme (WMCL) [21]. The WMCL improves the localization accuracy of MCB by using the location information of both normal and anchor nodes to generate and weight the candidate samples. The sampling efficiency is improved via location information of the blind node in the current time slot and its neighboring normal nodes location information in the previous time slot. The location information of the normal node comprises a sample set and maximum possible error of the estimated position in the x- and y- axes.

The WMCL is further improved in another method called the RMCB where it includes additional constraints of negative information to reduce the sample area, In this regard, RMCB uses both positive and negative anchor nodes constraints[22]. Contrarily, COMCL, PMCL, evaluates the distance and direction of the anchor node movement to decrease the scope of the sample area[23][39].

The Improved MCL (IMCL) scheme enhances the localization accuracy by introducing normal node location information [24]. This scheme consists of three steps: sampling, neighbor constraint, and refinement. In the sampling step, the blind node generates samples by exchanging messages with the anchor node as in the previous schemes. Then, the normal nodes will broadcast their location information, which contains position and length of eight sectors. Finally, the samples are filtered based on anchor node constraint and movement direction of normal nodes. Finding the length of eight sectors in this scheme require additional number of calculations and broadcasting the eight sectors length can increase the communication cost [41].

Typically, the blind node receives redundant messages from the normal nodes without further enhancing its localization accuracy. Therefore, distance from the normal nodes to the blind node and its maximum localization error has been proposed as a criterion to narrow the redundant messages[25]. Transmission of the location information is inhibited when the normal node exceeds the threshold value or has minimal localization error.

Orbit[26] improves the sampling efficiency by using a special graph theory known as star graph, which contains five edges in which the intersection of the edges present the bounded sample area. However, Orbit is more complex than the SMC scheme because Orbit increases the communication and computational costs. Moreover, finding five neighbors of a blind node is not consistently applicable all the time.

The EDAL scheme can improve the localization accuracy and maximize the anchor nodes coverage by controlling the anchor node velocity based on overlap degree between them. The velocity in EDAL is the function of the overlap degree between the anchor nodes whereas the previous schemes using random waypoint mobility model. Thus, the EDAL can maintain the number of anchor nodes in neighbors to improve accuracy and optimize the overlap degree between anchor nodes.

Table 1:

Comparison of SMC localization schemes

Studies	Mobility model	Accuracy	Communication Cost	Computation Cost	Dependent on anchors
MCL	Waypoint	Low	Low	High	Full
MCB	Waypoint	Low	Low	Medium	Full
MSL*	Waypoint	High	High	High	Partial
LCC	Waypoint	High	Medium	High	Partial
WMCL	Waypoint	Medium	High	Low	Partial
COMCL	Waypoint	High	High	Low	Partial
RMCB	Waypoint	High	Medium	Low	Partial
IMCL	Waypoint	High	Medium	Medium	Partial
Orbit	Waypoint	High	High	High	Partial
EDAL	EDAL	Medium	Low	Medium	Full

The localization accuracy in pervious schemes is improved by increasing the anchor node density and by utilizing normal node location information as presented in Table 1. However, increasing the anchor node density will increase the cost, size, power consumption and the connectivity of anchor node. Moreover, the location information of normal node is susceptible to present of error (its estimated location) and will maximize the communication cost in the network. Thus, the efficient distribution in EDAL can control the number of anchor nodes in the neighbors to increase the anchor node coverage and improve the localization accuracy.

2.2 Mobility Model

A mobility model is a design that models the changes ofsensor node location, velocity, direction and acceleration over time. This changes will rapidly modifies the topology in mobile WSNs[7] that in a period of time will affect network coverage and connectivity [16]. Generally, mobility models can be categorized as random, predictable, and controlled. The detailed comparisons, strengths, and challenges of the mobility models in the literature are discussed in[27-29].

An adequate investigation with at least one sensor node is essential in WSNs. This issue is mainly because of the movement of sensors can affect the coverage area in two ways. The optimistic way is to transfer the mobile sensor to more discovered areas, communicates with the isolated sensor, and extends network life[30]. However, nodes in static networks use the same routing path all the time to communicate with the sink, which consumes more power of sink neighbors and causes a split between the network and isolated sink node. The negative approach of the movement originates from the data lost in the handover process when the network disjoints into two parts. Moreover, sensors with high-speed movement can frequently disconnect and decrease network performance and stability.

The waypoint model permits the mobile sensor to move forward independently from its neighbors and its previous position. Hence, the movable sensor chooses its direction and velocity randomly without any correlation to its neighbors [8]. Such movement flexibility may not be the cases for certain applications such as speed of vehicles, disaster relief, battlefield, and other applications. The fact is that there are applications that movement can be controlled and a level of dependencyoccurs between the velocity of the nodes in the neighbors[31,32]. Another drawback of the waypoint model is the convergence of nodes close to the center of the simulation area[33], which decays the velocity of the respective nodes [34,35].

In the previous literature, the waypoint model was typically used in range-free localization schemes [16]. The main properties of waypoint model is the sensor node only retainedthe maximum and minimum velocities due to a small memory capacity, and this simplicity has led to its usage in most of the previous studies. Pause time is an important parameter in the waypoint model [36]. In the waypoint model, the pause time is set to zero, in which the sensor nodes move continuously without pausing time.

The movement of sensor node is highly dependent on the reference point or leader in the reference point group mobility model (RPGM). However, the election of the leader requires a long process, and the loss of the leader will affect the robustness and stability of the networks. Another issue in the RPGM is that each sensor node must request the leader for direction and velocity of movement in each time slot [8], which increase the communication cost in the networks and overhead for the leader. Therefore, RPGM is only suitable for specific application, such as museum visitors and conference members[37].

The inefficient distribution in the random waypoint and high dependency in RPGM mobility models maximizes the overlap between anchor nodes without improving localization accuracy. Based on this observation, we proposed localization scheme EDAL to control the movement of the anchor nodes based on the number of anchors in the neighbors and the degree of overlap between the anchor nodes.

3. Proposed scheme EDAL

Generally, mobile anchor nodes are used in the range-free schemes to aid location estimation of the blind node. Thus, the anchor nodes distribution is a critical issue in the localization process. An efficient distribution can increase the coverage of anchor nodes and network connectivity with minimum number of anchor nodes, while a weak distribution will leads to an excessive anchor nodes that will increase cost and energy consumption[33].

The overlap between sensor nodes is a critical issue in WSNs connectivity. The minimum overlap is important in maintaining connectivity and conserving the robustness of the networks. In contrast, a large overlap produces redundant messages and consumes extra energy without improving localization accuracy. Another critical issue in the localization process is a number of anchor nodes in the neighbors. A typical localization process in 2D space requires three anchor nodes in the neighbors to estimate a blind node location[10][40].

Based on these observations, we implement an efficient localization scheme to distribute the anchor nodes with an optimal overlap degree. The main challenge when the anchor node has the flexibility to move randomly is that the blind node can find more than three anchor nodes in the neighbor or two anchor nodes with large overlap degree as depicted in Fig. 1[10,38]. The EDAL scheme can effectively resolve this problem by correlating the velocity of the anchor nodes and the anchor node number in the neighbors with its overlap degree. The optimum value of velocity can maintain the robustness of the WSNs and increase the coverage areas.

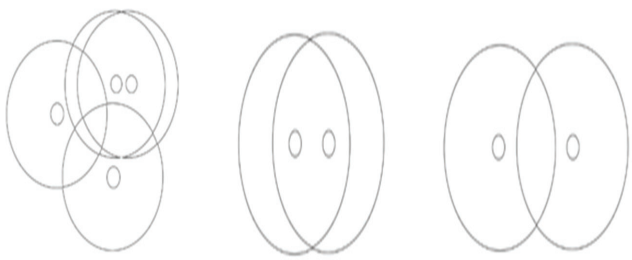

Fig.1.a Fig.1.b Fig.1.c

Fig.1.a

More than three anchor nodes in the neighbor

Fig.1.b

Two anchor nodes with extra overlap

Fig.1.c

Two anchor nodes with optimal overlap.

The velocity of the anchor node in EDAL scheme is set to maximum velocity (max-v) if a large overlap exist or more than three anchor nodes occur in the neighbors, whereas the minimum velocity (min-v) is chosen if small overlap occur, another velocity choose according to overlap degree (distance between anchor node) as presented in Algorithm 1. A small distance between two anchors nodes indicates a large overlap exist, whereas a large distance indicates a low overlap occur. Based on our simulation results, the distances between anchor nodes in the neighbors are divided into five periods and the velocity is associated with it, as in Algorithm 1. In this study, we used the minimum overlap of 1.73R as in[10].

Algorithm 1. A framework of EDAL localization algorithms.

Initial phase:

1. Find the number of anchor node in the neighbor (NA)

2. Calculate the distance between anchor nodes in the neighbors (The overlap degree (OD))

Velocity calculation phase:

If NA >= 3 or OD<=0.25R then velocity= max_v;

Else if OD> 0.25R and OD<= 0.50R then velocity= max_v * 0.75;

Else if OD> 0.50R and OD<= 0.75 R then velocity= max_v * 0. 50;

Else if OD> 0.75R and OD<= R then velocity= max_v* 0.25;

Else if OD> R and od< =1.75 R then velocity= min_v;

If OD < 1.75R then velocity= selected randomly;

Where R is the communication range, max_ is maximum velocity and min_v is minimum velocity.

4. Experimental setup and results

We tested the performance of EDAL scheme using various simulation parameters to verify its efficiency and compared it with previous localization schemes: MCL, MCB, MSL*, WMCL, and WMCLB schemes. The Java-based simulator code of MCL, MCB, and MSL* are received from the original authors, whereas WMCL, WMCLB and EDAL are implemented in the same simulator code provided by MCB authors[20].

4.1 Experimental setup

The normal nodes were set to move randomly based on the waypoint model and the anchor nodes were set to move based on the EDAL assumption. Anchor node density (Ad) is the number of anchor nodes in the first and second hops, whereas normal node density (Nd) is the number of anchor and normal nodes in the first hop.

In this experiment, the MCB scheme was selected to measure the performance of EDAL because it uses only anchor nodes observation in the localization process while other schemes use both anchor and normal nodes to improve localization accuracy. The use of normal nodes can increase communication costs and the overhead in the networks, moreover the location information of normal node is estimated location that impeded with the present of error. For these reasons, MCB was selected to measure the coverage of EDAL. Moreover, the MCB scheme also has an advantage over MCL in sample efficiency.

The EDAL scheme includes three important parameters: the degree of overlap between anchor nodes, the density of anchor nodes, and the velocity of the anchor node. The effect of each parameter is measured by several simulation tests and compared with MCB scheme over two different mobility models: waypoint and RPGM. The appropriate parameter values are selected and applied in the simulation.

The value of each parameter is calculated by executing 30 networks randomly. We simulated 1,000time units in each network, and then the time unit was averaged between 600 and 1,000 to assess each value. Each data point presented in this study was averaged by 30 independent experiment results. Other important parameters used during the simulation were the boundary of simulation area, which was set as 500 unit*500 unit, and the communication range (R) for anchor and normal nodes at 50 units. Time is a discrete time unit. In the initial setup, all sensors were distributed randomly over the simulation area. The pause time is set to zero, max-v is 0.2R, the number of samples is 50, Ad = 1and Nd =10, and the minimum overlap is 1.73R.

4.2 Experimental Results

The experimental results are described in two sub-sections. The first sub-section describes the coverage of the EDAL scheme in different overlap degrees and different anchor node densities. The second sub-section explains the measurement value of location accuracy in different velocity values, anchor nodes, normal nodes densities, and degrees of irregularity. Note: the MRPGM and M Waypoint means MCB scheme using RPGM and waypoint mobility model, respectively.

4.2.1 Coverage of EDAL scheme

The degree of overlap is measured by Euclidean distance, in which the small value of this similarity measure implies a large overlap between the anchor nodes and vice versa[10]. For example, a distance value lower than 0.1R indicates a substantial overlap, whereas a distance value near than1.73R indicates the optimal overlaps. The threshold value of the overlap degree is essential in ensuring the network stability. In this study, the threshold value of the overlap was set at1.73R as in [10].

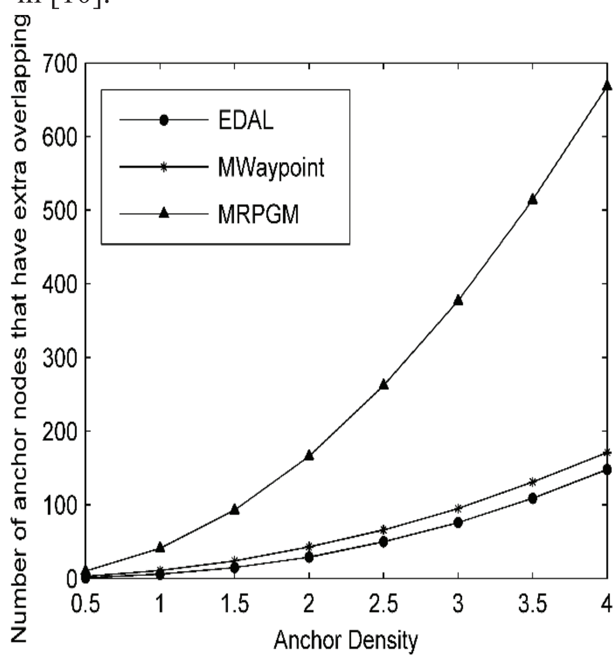

Fig. 2.

The relationship between anchor density and a number of anchor nodes with extra overlap.

The possibility of large overlap occurrence between the anchor nodes or finding more than three anchor nodes in the neighbors increase when the density of anchor nodes increases, as shown in Fig. 2. However, EDAL uses control velocity with the overlapping degree to optimize these overlaps and maximizes the coverage area with the same number of anchor nodes when compared with localization scheme using waypoint model. The inefficient distribution of anchor nodes in the waypoint and RPGM models increase the number of anchor nodes that have extra overlap. The group coherent almost requires minimum distance between neighbors that can produce huge overlap, as in RPGM. In the RPGM model, the increased of anchor node density can enormously increase the overlap degree because the localization parameters: velocity and direction of the anchor nodes are maintained based on the group leader decision.

Table 2:

Number of anchor nodes with extra overlap.

Mobility Model	Localization scheme				
	MCL	MCB	MSL*	WMCL	WMCLB
RPGM	41	41	42	42	41
Waypoint	10	11	10	10	10
EDAL	6	6	6	5	6

Different localization schemes (MCL, MCB, MSL*, WMCL, WMCLB) are used to examine the efficiency of the EDAL. The performances of these schemes are listed in Table 2 and 3. Table 2 presents the number of anchor node with extra overlap degree in different localization scheme based on RPGM, waypoint mobility models and EDAL assumption and Table 3 presents the localization accuracy. The number of anchor node with large overlap is highly affected by mobility model type and slightly affected by variation of the localization scheme. These results showed the importance of controlling anchor node velocity in its distribution. EDAL can optimize the number of anchor node with extra overlap degree in each localization scheme with 50% while maximizing the coverage area as compared to the waypoint model. The RPGM model has the highest number of extra overlap degree in all schemes.

Table 3:

Localization accuracy in different schemes.

Mobility Model	Localization scheme				
	MCL	MCB	MSL*	WMCL	WMCLB
RPGM	0.55	0.54	0.42	0.48	0.39
Waypoint	0.56	0.56	0.31	0.38	0.40
EDAL	0.51	0.51	0.28	0.34	0.35

Similarly, the results in Table 3 showed that the localization accuracy can be improved by controlling the anchor nodes velocity. The performance of the EDAL attained the highest localization accuracy among the tested schemes.

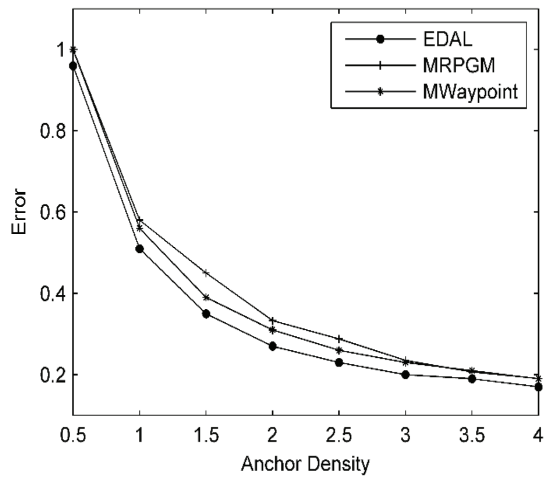

Fig. 3.

Anchor node density and localization error.

The increase of anchor node density can improve the localization accuracy in all schemes, as shown in the figure 3. EDAL is capable of improving the localization accuracy faster in all cases with optimal number of anchor nodes. In the MRPGM, the localization accuracy is less improved because the blind node requires to ask the group leader for location information per each time slot. The localization accuracy in the Waypoint also improved less when compared with EDAL.

From this results, we can show the important of anchor node distribution and how much the random movement can produce large overlap without improving the localization accuracy.

4.2.2 Localization Accuracy

Accuracy is the most important parameter in the localization process. For this, the accuracy of EDAL scheme measured based on the effective parameters: anchor node density, normal node density, velocity, and degree of irregularity.

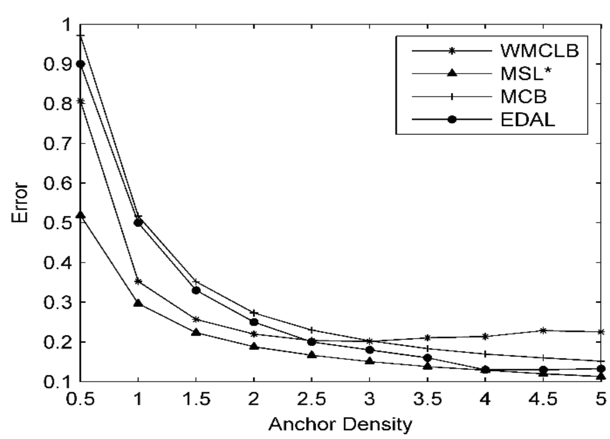

Fig .4.

Accuracy and anchor node density.

Anchor node density: In Fig. 4, the localization accuracy of EDAL and MCB rapidly improved with the increasing of anchor nodes density because they draw observations primarily from the anchor nodes. Other schemes that draw observations from the anchor and normal nodes, such as MSL* and WMCLB, are less affected by the increment of anchor node density. Nevertheless, the increment of anchor node density can be reflected negatively in the power consumption and dependency on hardware such as GPS. EDAL has a capability to improve the localization accuracy comparable with other schemes in the case of large anchor nodes density, results in Fig.4 show that at the anchor node density equal to 4, EDAL can improve the localization accuracy more than other schemes even it use normal node location information like MSL* and WMCLB.

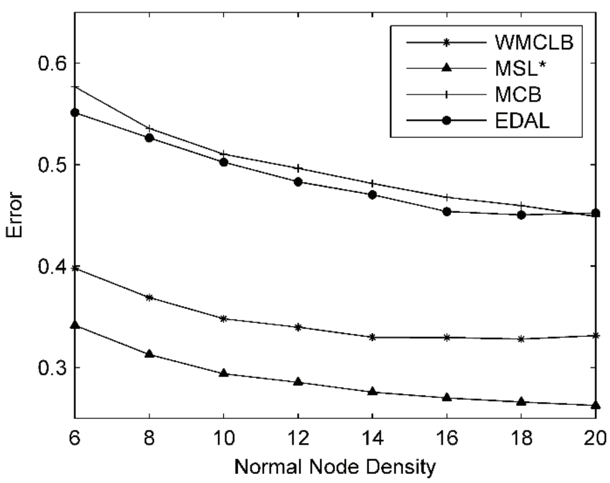

Fig. 5.

Accuracy and normal node density.

Normal node density: Localization accuracy can be improved with the increment of normal node density, as shown in Fig.5.The observation on EDAL and MCB only shows small percentage of improvement when the normal nodes increases. This is because both methods broadcast the location of anchor nodes to the first and second hop sensors in the neighbor. However, MSL* and WMCLB shows the opposite reaction because they draw observations from both anchor and normal nodes in the neighbors. MSL* is more effective than WMCLB because it uses all normal nodes samples in the first and second hops to draw observations with high communication costs. WMCLB uses bounded box over normal nodes to improve sampling efficiency and filter out the invalid samples. Thus, it is more sensitive to changes in normal node density.

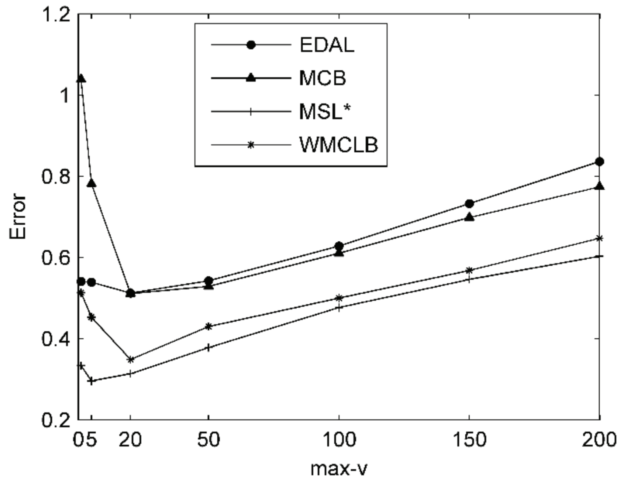

Fig. 6.

Accuracy and velocity of sensor nodes.

The velocity of nodes: Fig.6 shows that the movement of sensor nodes can improve the localization accuracy by receiving new anchor nodes and finding more observations. Movement with limited velocity can further improve the localization accuracy because the blind node can use some previous location information in the last time slot. A thigh-velocity, sensor can move to a farther distance from the previous location, thus the location information in previous time slot cannot improve the localization accuracy. Fig.6 shows that all schemes have high accuracy at velocity equal to 20.This value is used throughout this study as default value for velocity.

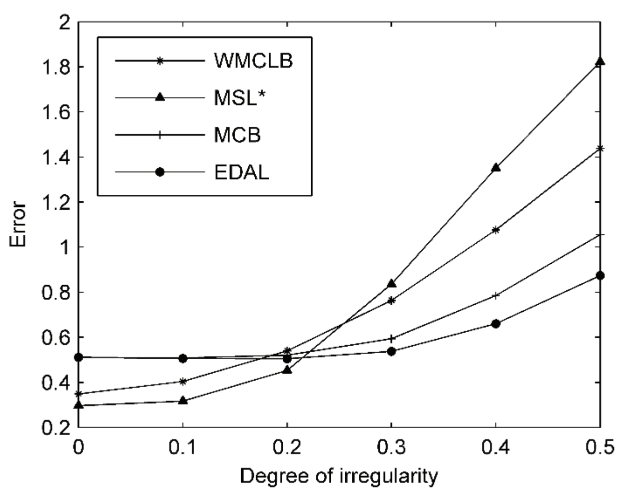

Fig. 7.

Accuracy and degree of irregularity.

The degree of Irregularity (DOI): Fig.7 shows the effects of DOI on localization accuracy wherein the increase of DOI minimized the localization accuracy in all schemes. However, in real-world applications, the signals can be interrupted by noise and affected by antenna direction and natural phenomena such as humidity and walls. In some cases, the distance between two sensor nodes is nearly half the radio range; in this case, they cannot communicate because they share a large variation of radio range. A full circle in EDAL was used during the experiments to present the communication range of the sensor nodes.

5. Conclusions and future work

The random velocity used in previous schemes based on waypoint mobility model has a large overlap between the anchor nodes that consumed more power and reduced the coverage area without improving the location accuracy. However, the EDAL can distribute the anchor nodes efficiently using the adaptive velocity with overlapping degree between the anchor nodes in the neighbors. Nevertheless, the patterns of movement remains an open research area in mobile WSNs. In future, we intend to extract the features of the mobile node movement from the real experiment and implement EDAL in real experiments to measure its efficiency.

Acknowledgments

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In vitro and In vivo Evaluation of a Plant Origin Acaricide and In vitro Evaluation of Plant Extracts Against Two-Spotted Spider Mite, Tetranychus urticae Koch

التقييم المخبري والحقلي لمبيد أكاروسي من أصل نباتي والتقييم المخبري للمستخلصات النباتية على الأكاروس العنكبوتي ذو البقعتين، Tetranychus urticae Koch

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Abstract

This study was performed at Sweida Research Center/GCSAR/ in Syria during 2016. The effect of garlic and soft wheat crude extracts as well as the effect of matrine (plant-based acaricide), jolly and sanmite (chemical-based acaricides) were tested under in vitro conditions on two-spotted spider mite, Tetranychus urticae Koch (TSSM). In addition, acaricides used were evaluated under in vivo conditions. Survival % of TSSM was calculated, neglog transformed and subjected to ANOVA analysis using Tukey HSD test. In vitro bioassay results revealed a significant effect of garlic and wheat extracts as well as matrine, jolly and sanmite. After 72 hours, no difference was observed between plant extracts, and among tested acaricides. In vivo bioassay results also showed a significant effect of acaricides used where jolly was the best and matrine and sanmite were comparable. These findings support the idea of using plant-based acaricides (including lectin-based acacicides) as an alternative strategy of using chemical-based acaricides. Taking into account the advantages of in vitro bioassays and based on the results of this study, we suggest predicting in vivo response from in vitro results although this issue needs to be tested first for the crude plant extracts to evaluate their stability under in vivo conditions.

Keywords: Spider Mite, Plant Extract, Matrine, Survival %, Lectin.

ملخص:

نُفذت هذه الدراسة في مركز بحوث السويداء/ الهيئة العامة للبحوث العلمية الزراعية، سورية خلال العام 2016. وجرى اختبار تأثير المستخلص الخام لكل من القمح الطري والثوم، بالإضافة إلى الماترين (مبيد أكاروسي من أصل نباتي) والجولي والسانمايت (مبيدات أكاروسية من أصل كيميائي) على الأكاروس العنكبوتي ذي البقعتين Tetranychus urticae Koch تحت الشروط المخبرية. بالإضافة لذلك، جرى تقييم المبيدات الأكاروسية المختبرة تحت الشروط الحقلية. حُسبت % النجاة للأكاروس العنكبوتي ذي البقعتين، ثم حُولت البيانات وعُرِّضت لتحليل التباين باستخدام اختبار Tukey HSD. بينت نتائج الاختبارات الحيوية المخبرية وجود تأثير معنوي لمستخلصي الثوم والقمح بالإضافة إلى الماترين والجوليوالسانمايت. لم تُلاحظ وجود فروقات فيما بين المستخلصات النباتية المستخدمة، وفيما بين المبيدات الأكاروسية المستخدمة بعد 72 ساعة. كما بينت نتائج الاختبارات الحقلية وجود التأثير المعنوي للمبيدات المستخدمة حيث كان المبيد جولي الأفضل، بينما كان تأثير الماترين والسانمايت متشابها. تدعم هذه النتائج فكرة استخدام المبيدات ذات الأصل النباتي (بما فيها المبيدات ذات الأصل اللاكتيني) كإستراتيجية بديلة عن استخدام المبيدات ذات الأصل الكيميائي. آخذين بالاعتبار إيجابيات الاختبارات المخبرية ونتائج هذه الدراسة، نقترح إمكانية التنبؤ عن الاستجابة في التجارب الحقلية انطلاقا من نتائج التجارب المخبرية على الرغم أن هذا التنبؤ يحتاج لاختبار فيما يخص تأثير المستخلصات النباتية الخام لتقييم ثباتها تحت الشروط الحقلية.

الكلمات المفتاحية: الأكاروس العنكبوتي، المستخلص النباتي، ماترين، % النجاة، اللاكتين.

Introduction

Secondary pest outbreak is caused by using broad-spectrum insecticides that disrupt natural pest control due to the toxicity of these insecticides on non-target biological enemies. This is the case for two-spotted spider mite (TSSM), Tetranychus urticae (Koch). TSSM has a wide range of hosts (more than 1200 species), 150 of them are economically significant (Zhang, 2003).The population of these mites can reach high density quickly, and subsequently reduces the quality and quantity of crops especially after sever infestations.

Mites feed on the leaves by sucking the plant sap. As a result, the photosynthetic efficiency decreases due to the loss of chloroplasts and this eventually will lead to leaf death (Tanigoshi et al. 2004).

As conventional insecticides are used in several agro-ecosystems (Sarwar, 2015) and because TSSM has turned to be a key pest at present, agriculture is facing a serious problem. Spider mites have developed resistance to pesticides rapidly where resistance to over 80 pesticides covering most major chemical groups has been reported (APRD, 2007).It is worth mentioning that TSSM populations (and other mites) have the highest occurrence of pesticide resistance among arthropods in agricultural habitats (Van Leeuwen et al., 2015). In addition, some of insects' biological enemies are sensitive to pesticides (Zanuncio et al., 1998), which will decrease their efficiency for biological control (Biondi et al., 2015). These concerns have directed researchers' attention to search for alternative control methods such as natural pesticides derived from plants (Isman, 2006). Plant extracts are one of the non-chemical control options that have recently received more attention. There are several reports on botanical acaricides proved to be effective against TSSM like neem (Martinez-Villar et al., 2005) and garlic (Boyd and Alverson, 2000).

Biological control and plant-based pesticides are important for developing an Integrated Pest Management Program (Jansen, 2013). Hence, using plant-based pesticides could be an effective strategy to control pests and reduce negative effects of synthetic pesticides.

Therefore, this study focuses on the effect of three acaricides (one of them is derived from plant origin) on TSSM under laboratory and field conditions as well as the effect of two plant extracts under laboratory conditions. In addition, this study addresses the possibility of predicting the in vivo response starting from the in vitro results.

Methods and materials

This study was performed at Sweida Research Center/ GCSAR/ Syria during 2016. The in vivo bioassay was achieved in a homogenized apple field with the following characteristics: soil: loamy clay, apple cultivar: Starkrimson (the age is unified: 30 years) grifted on the rootstock MM 109, altitude: 1550 meter above sea level, average of annual precipitation: 550 millimeter, the weather is hot, dry in summer, and cold in winter.

Preparation of tested acaricides and plant extracts

The toxicity of certain acaricides (matrine is a plant-based acaricide whereas jolly and sanmite are chemical-based acaricides), along with water as a control was tested using the manufacturer recommended concentrations (Table 1) under in vitro and in vivo conditions. In addition, the effect of garlic and soft wheat crude extracts was also tested under in vitro conditions where extraction buffer (0.2 M Nacl) was used as a control. Ten grams from each of the garlic gloves and wheat grains (Bohuth 8: soft wheat) were homogenized in 80 ml of extraction buffer following the ratio 1 to 8 (w/v) (Hou et al., 2010). The homogenates were left at room temperature for 24 hours (H) with stirring several times. Afterwards, the homogenates were filtered using a filter paper, and the resultant solutions were kept at 4° C until use.

Table 1.

Acaricides used and their application rate

Trade name	Effective ingredient	Application rate
Matrine	Matrine 0.5%	100 cm3/ 100 L water
Jolly	Fenbutatin oxide 50%	100 cm3/ 100 L water
Sanmite	Pyridaben 20%	100 g/ 100 L water

Preparation of TSSM

TSSMs were collected from several apple orchards at Sweida Research Center/GCSAR, where no pesticides were used. The mites were brought into a greenhouse and were released on potted kidney bean plants (Phaseolus vulgaris L).

In vitro bioassay

The in vitro bioassay was performed following the method of Sikha et al (2011) with some minor modifications. Complete randomized design with six replications was used for this assay. Apple leaf disks (2 cm diameter) were immersed in each of the different solutions used, and immediately air-dried for ½ H. After that, leaf disks were put in petri plates (9 cm diameter) on wet cotton to keep them turgescent. TSSM adults were collected from the culture and moved to the leaf disks/ 10 mites on each leaf disk/ 3 leaf disks per plate/ 6 plates per treatment at room temperature. Mites regularly observed after 24, 48 and 72H by stereomicroscope. Mites were considered dead when not showing any movement.

In vivo bioassay

Randomized complete block design with three replications was used for the in vivo bioassay. Applied treatments were the three tested acaricides and water as a control. TSSM population (adults and nymphs) was registered on 3 replicates/ 3 trees per replicate/10 leaves per tree (from different parts of the canopy) for each treatment before the spray in addition to 3, 7, 10, 15 and 21 days after spraying. The leaves were passed through a mite-brushing machine and afterwards placed onto a circular glass plate that is coated with a thin layer of glycerol to catch the mites (Henderson and Mc Burnie, 1943).

Data collection and analysis

For both bioassays, the number of living adults (moving stages: adults and nymphs for the in vivo bioassay) was converted into survival % which subsequently neglog transformed (Whittaker et al., 2005) and finally subjected to analysis of variance (ANOVA).Neglog transformation is normally used to reduce the heterogeneity of the data especially when performing bioassays and using percentage data. This method has been used before (Belay et al., 2018). Survival %was expressed as means ± standard deviations. The means were compared using Tukey HSD test at 0.01 probability level for the in vitro bioassay and at 0.05 probability level for thein vivo bioassay by using the SPSS program version 19.

Neglog = (sign X) * Ln (|X| + 1). X is survival %.

Results and discussion

Effect of acaricide and plant extract treatments under in vitro conditions

The effect of several acaricides including matrine (a natural-based acaricide extracted from wild medicinal plant, Sophora flavescens Ait), jolly and sanmite (chemical-based acaricides) was evaluated under in vitro conditions at different time points. ANOVA results showed a significant effect of acaricide application on the survival % of TSSM as compared to the control (Fig 1, Table 2). No difference was observed after 24 H among tested acaricides whereas only matrine reduced the survival % significantly compared to the control after 48 H. All tested acaricides showed significant differences compared to the control after 72 H but no difference was registered among them (Fig 1).

The survival % of the control treatment (only water) was registered 91%, 88%, 78% after 24H, 48H and 72H, respectively (Fig 1).

Table 2.

Mean square of survival %(transformed data) for tested acaricides under in vitro conditions after 24H, 48H and 72H

Source of variance	d.F	24H	48H	72H
Treatment	3	0.028	0.786**	1.176**
Error	20	0.01	0.01	0.073

**: indicates significant differences at P-value < 0.01

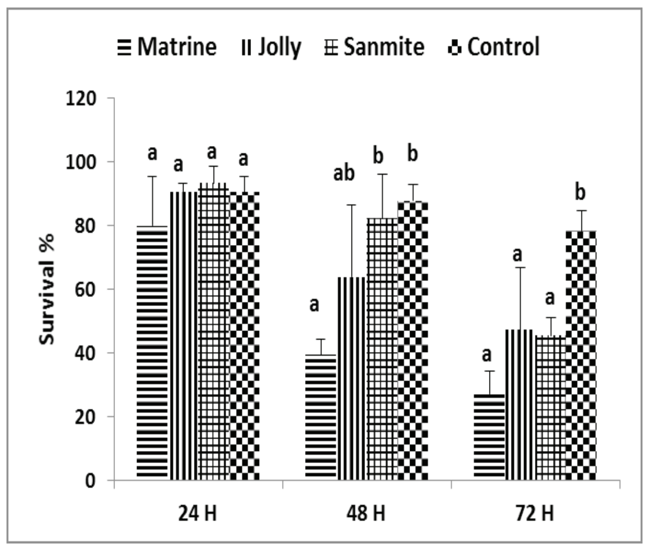

Fig. 1.

Survival % of TSSM adults after immersing leaf disks in tested acaricides: matrine, jolly, sanmite and water as a control. The survival % after 24hours (H), 48 H and 72 H is shown. Bars represent means ± standard deviation based on 6 replicates (plates)/three leaf disks per plate/10 adults per leaf disk. Within each group (24H, 48H or 72H) different letters indicate significant differences at P-value < 0.01 (Tukey test).

Crude extract effect for garlic gloves and soft wheat grains was also tested under in vitro conditions. Both extracts had significant effect compared to the control especially after 72H although no difference was observed between the two tested extracts (Fig 2, Table 3). After 24H, the effect of tested extract was comparable to the control, but only garlic extract shows significant effect on TSSM survival % after 48H proving its rapid efficacy compared to wheat extract (Fig 2).

The survival % of the control treatment (0.2 M Nacl) was registered 94%, 78%, 56% after 24H, 48H and 72H, respectively (Fig 2). This reduction can be explained by the effect of Nacl, which is apparently greater than the effect of only water especially after 72H (56% for the salt treatment and 78% for water treatment). The reduction of survival % in both controls might also be due to the insufficient food (only 2 cm diameter leaf disks were used). In addition, the in vitro bioassay was performed at room temperature, which is not optimum for TSSM. Under field conditions, the average maximum temperature in June, July and the first half of August (2016) was 30°±2.4° C (Climate Measuring Station/ Sweida Research Center).

The effectiveness of garlic and wheat crude extracts is most probably due to the effect of lectins, even though the effect of other components cannot be excluded. The activity of lectins, which are carbohydrate-binding proteins, against insects was proven and received a lot ofattention (Vandenborre et al., 2011; Bharathi, 2017).Constitutively expressed lectins are often concentrated in seeds or vegetative storage tissues, and they probably act as storage proteins (Van Damme et al., 1998). However, in case of pest attack they play a role as defense-related proteins against pathogens and insects (Roy et al., 2014). Garlic gloves and wheat grains contain lectins called Allium sativum agglutinin, and wheat germ agglutinin, respectively. Their insecticidal activity has been reported in transgenic plants (Sadeghi et al., 2007), and by using the lectin in artificial diets (Harper et al., 1998), or by using the purified lectin in bioassays (Roy et al., 2008).

Table 3.

Mean square of survival % (transformed data) for tested plant extracts under in vitro conditions after 24H, 48H and 72H

Source of variance	D.F	24H	48H	72H
Treatment	2	0.014	0.191**	0.971**
Error	15	0.005	0.026	0.077

**: indicates significant differences at P-value < 0.01

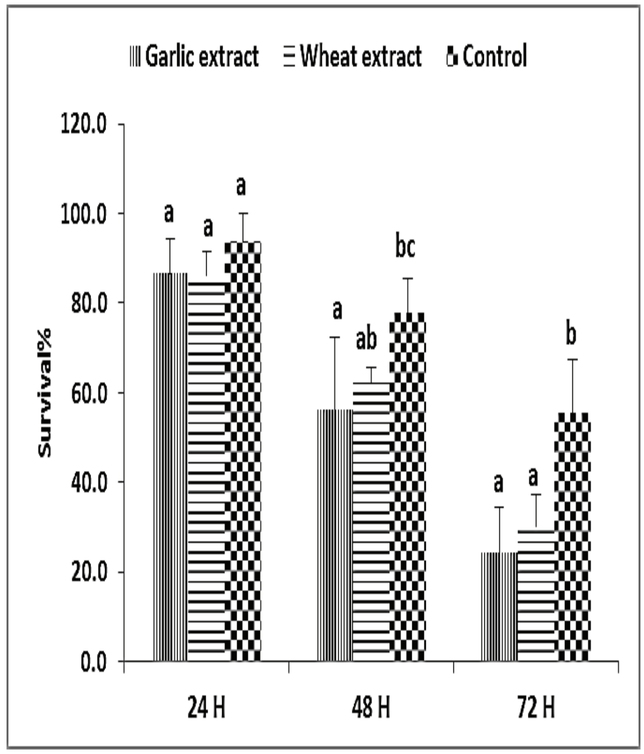

Fig. 2.

Survival % of TSSM after immersing leaf disks in tested plant crude extracts: garlic extract, wheat extract and 0.2M Nacl as a control. The survival % after 24H, 48H and 72H is shown. Bars represent means ± standard deviation based on six replicates(plates)/ three leaf disks per plate/ 10 adults per leaf disk. Within each group (24H, 48H or 72H) different letters indicate significant differences at P-value < 0.01 (Tukey test).

Effect of acaricide treatments under in vivo conditions

The acaricide treatments were effective in controlling TSSM population under in vitro conditions. Therefore, a bioassay was conducted to evaluate their effect under field conditions, and to compare the effect of the plant origin acaricide with the chemical-based acaricides. The results revealed a significant reduction in survival % of TSSM moving stages at 3 days (D), 7D and 10D after spraying for all tested acaricides(Fig 3, Table 4). At the three mentioned time points, Jolly was the most effective acaricide against moving stages of TSSM (survival %: 5.1%, 2.6%, 0.4% at 3D, 7D, 10D respectively, P-value < 0.05). It is not surprising that jolly was more effective than matrine under field conditions (they were comparable after 72H under in vitro conditions, Fig 1) because only adults were observed for thein vitro bioassay whereas moving stages (adults and nymphs) were registered for thein vivo bioassay. Additionally, both bioassays were assessed at different durations (3 days for the in vitro bioassay and 21 days for the in vivo bioassay).

In general, using matrine is safe to beneficial arthropods and to the environment (Wang et al., 2012) because its plant origin. In addition, registering no significant difference between matrine and sanmite (Fig 3) supports the idea of using matrine instead of synthetic pesticides. Furthermore, the effective ingredient of matrine is very low 0.5% compared to 50% of jolly and 20% of sanmite (Table 1). This means that there is a possibility to increase the effective ingredient of matrine to be more efficient although this issue has to be proven first. Matrine is a quino lizidine alkaloid extracted from Sophora flavescens (Liu et al., 2008). In accordance with our results, matrine has been reported to be effective against mites (Niu et al., 2014).Taking into account the high toxicity of chemical origin pesticides towards the environment, biological enemies, animals (Mahmood et al., 2016) and human beings (Nicolopoulou-Stamati et al., 2016), there is a continual need to use safer alternatives particularly plant origin pesticides.

Table 4.

Mean square of survival % (transformed data) for tested acaricides under in vivo conditions 3, 7 and 10 days after spraying

Source of variance	D.F	3D	7D	10D
Treatment	3	4.476*	3.628*	3.760*
Block	2	0.018	0.068	0.017
Error	6	0.064	0.022	0.060

*: indicates significant differences at P-value < 0.05

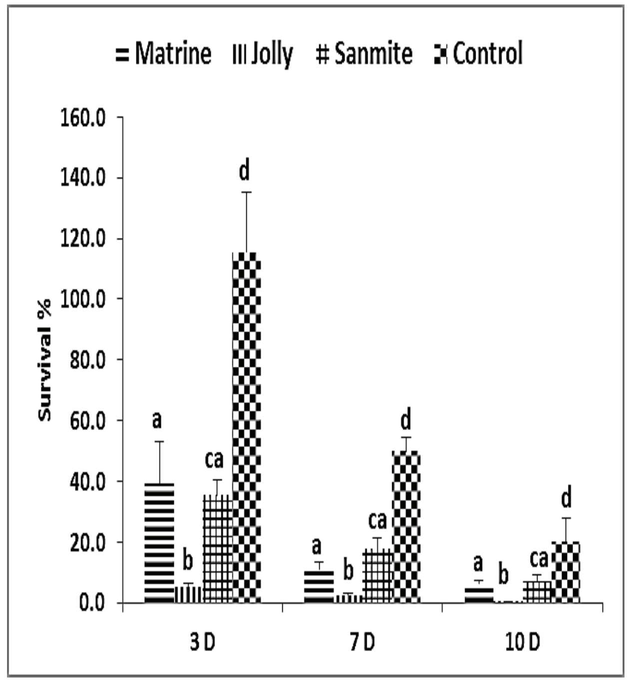

Fig. 3.

Survival % of TSSM for in vivo bioassay after spraying with tested acaricides: matrine, jolly, sanmite and water as a control. The survival % after 3 days (D), 7D and 10D is shown. The average of moving stages number before spraying were 476, 513, 967 and 383 for matrine, jolly, sanmite and control treatments, respectively. Bars represent means ± standard deviation based on 3 replicates/ 3 trees per replicate/ 10 leaves per tree. Within each group (3D, 7D or 10D) different letters indicate significant differences at P-value < 0.05 (Tukey test).

Even though observation was registered, 15D and 21D after spraying, obtained data were not subjected to ANOVA because the mean number of TSSM in the control treatment was reduced naturally (Fig 4). This reduction in TSSM number is probably due to the high maximum temperature registered during the second half of the in vivo bioassay (36.2° ± 0.9° C), whereas it was 30° ± 1.9° C during the first half of the bioassay (Climate Measuring Station/ Sweida Research Center). The field experiment was deliberately started when the number of TSSM reached the highest values at the late season. This may also explain the reduction of TSSM number (control treatment) because TSSMs started entering the diapause period at the late season.

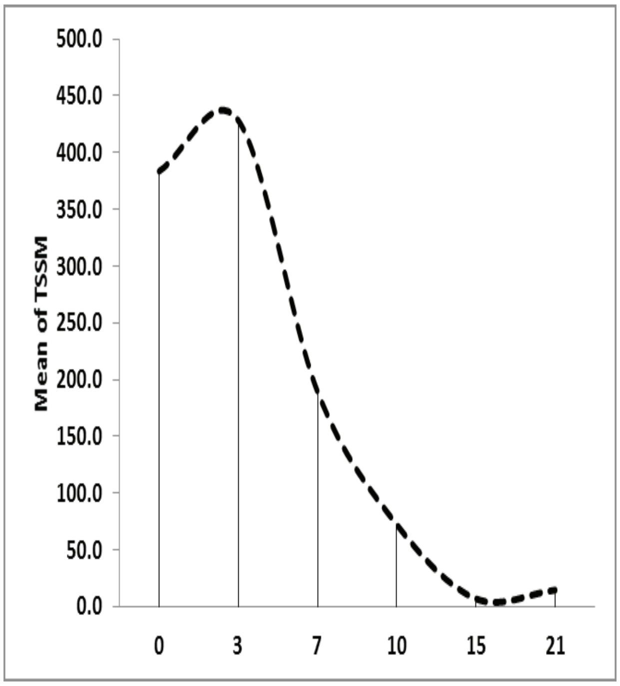

Fig. 4.

Mean of TSSM number (moving stages) in the control based on 3 replicates/ 3 trees per replicate/ 10 leaves per tree for the in vivo bioassay. Horizontal axis represents the time points (in days) of observations.

Prediction of in vivo response from in vitro bioassay results

In vitro bioassays have the potential to yield very important data but extrapolation to in vivo responses remains a major challenge. In vitro bioassays are easy to perform, rather cheap and not time and labor consuming. In addition, large numbers of treatments can be performed in a small place. On the contrary, in vivo bioassays are expensive, difficult to conduct, and time and labor consuming. This encourages researchers to test their treatments under in vitro conditions first especially that in vitro bioassays can screen their treatments before testing them in the field. It has been reported that the results of in vitroare still true for in vivo (Pokle and Shukla, 2015; Reddy et al., 2014).

Back to the issue raised by this study: can in vitro results be generalized to field conditions? Based on the results of this study and on some reports (Mamun et al., 2014), the answer is yes although this issue is still a prediction. At least, treatments can be screened and selected under in vitro conditions before being tested under in vivo conditions.

In the present study, plant extracts proved to be efficient under in vitro conditions but before this result can be generalized to field conditions their stability under field conditions has to be proven. This stimulates further researches to test this issue especially that plant extracts (rich in lectins like garlic and wheat) will pave the way of using acaricides derived from these extracts.

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Using Linear Mathematical Programming Model to Reduce Feed Cost of Broiler Farms

استخدام نموذج البرمجة الخطية الرياضية لتقليل تكلفة العلف في مزارع الفروج

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The research is based on a Master’s thesis

البحث مستل من رسالة ماجستير

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Abstract:

This research aims at shedding light on the effectiveness of using linear mathematical programming models in the production management of Broiler farms, and proposing the optimal low-cost Broiler feed mix within the constraints of the available feed resources. The research also aims at studying the effect of the low cost of the mixt on the proposed financial evaluation indicators. Primary data were collected through a random sample of broiler chicken farmers to obtain data related to the production costs, revenues and technical operations during the production season of 2018 in the governorate of Swaida, Syria. The results showed that the total cost of one ton of the proposed starting batch, obtained by using the linear programming model, was 196,953.93 SYP/ton, meaning the cost decreased by 16.2%. While the total cost of one ton of the final mix proposed for the linear programming model amounted to 191324.8 SYP/ton, the cost decreased by 16.8%. Through analyzing the impact of feed costs' decline by 16% on the financial assessment indicators of the sample, it can be noted that the variable expenses decreased to 7,205,866 SYP/farm in the summer production cycle and to 8,150,358.4 SYP/farm in the winter production cycle. The value of the net income index and the gross margin increased to 9,214,777.9 SYP/farm and 1,206,278.04 SYP/farm respectively for the mix obtained by the programming model. The revenue to costs ratio increased to 1.123%, and the operating ratio decreased to 0.89%. Moreover, it was noted that the profitability of the invested SYP increased to 12.3%, and the time of the variable assets turnover decreased to 312.66 days.

Keywords: Linear Mathematical Programming, Optimal Diet, Broiler Chicken, Economic Indicators, Production Costs.

ملخص:

يهدف البحث إلى إلقاء الضوء على فعالية استخدام نماذج البرمجة الرياضية الخطية في إدارة الإنتاج لمداجن الفروج، واقتراح أفضل تركيبة علفية للفروج تخفض التكاليف، ضمن قيود الموارد العلفية المتاحة، ودراسة تأثير انخفاض تكلفة الخلطة المقترحة في مؤشرات التقييم المالي المدروسة، وقد جرى الاعتماد على بيانات أولية، من خلال عينة عشوائية من مربي فروج اللحم للحصول على بيانات متعلقة بتكاليف الإنتاج والإيرادات والعمليات الفنية للموسم الإنتاجي 2018 في محافظة السويداء السورية، وبينت النتائج أن: إجمالي تكلفة الطن من الخلطة البادئة المقترحة بتطبيق نموذج البرمجة الخطيّة بلغ 196953.93 ل.س للطن، أي انخفضت التكلفة بنسبة 16.2%. في حين أن إجمالي تكلفة الطن من الخلطة الناهية المقترحة لنموذج البرمجة الخطيّة بلغ 191324.8 ل.س للطن، أي انخفضت بنسبة 16.8%، وبدراسة أثر انخفاض تكلفة العلف 16% في مؤشرات التقييم المالي المحسوبة للعينة، ويلاحظ أن قيمة التكاليف المتغيرة انخفضت إلى 7205866 ل.س للمدجنة في الدورة الصيفية، وإلى 8150358.4 ل.س للمدجنة في الدورة الشتوية. وقيمة كل من مؤشر صافي الدخل والهامش الإجمالي ازدادت إلى 921477.9 و 1206278.04 ل.س/للمدجنة للخلطة المستخرجة بنموذج البرمجة، وارتفاع قيمة نسبة الإيرادات للتكاليف إلى 1.123%، ونسبة التشغيل التي انخفضت إلى 0.89%، في حين أن أربحية الليرة المستثمرة ارتفعت إلى 12.3%، وزمن دوران الأصول المتغيرة قد انخفض إلى 312.66 يوم.

الكلمات المفتاحية: البرمجة الخطية الرياضية، عليقة مثلى، الفروج، مؤشرات اقتصادية، تكاليف إنتاج.

Introduction

Broiler farming is considered an economic advantage, placing the poultry sector within the top industries as it increases the amount of protein in the person's diet, contributes in (gross national income) GNI, does not require massive space for its production, has high manufacturing efficacy, and has quick turnover of the invested capital and short lifespan (45-55 days) (Al-Jojo, 2006). It is important for countries like Syria, which is characterized by increased population growth, limited natural resources and a challenging climate, to optimize the use of the available resources and foster the concept of sustainability to have constant economic growth. This requires the implementation of policies that are based on resources productivity assessment in the sector of agriculture, in order to reach the maximum level of resources' economic revenues, while maintaining the resources' productivity. Thus, production policies in Syria should seek to establish the highest possible level of resources' productivity in the most efficient and economic manner (National Agricultural Policy Center, 2002). Farm planning seeks to distribute economic resources in a way that guarantees the optimal use of these resources in accordance with the present capabilities and conditions. Thus, linear programming is considered one of the most important planning methods to find the optimal approach for utilizing resources for a project (Al-Ashari, 2011).

Research Importance and Justification

Broiler farming is considered an agricultural activity that is influenced by various factors and uncontrolled external variables such as, climate change, environmental fluctuations, diseases, price fluctuations of production inputs and extent of openness to global markets. Consequently, chicken farmers have multiple production targets that are subject to a number of constraints related to the availability of economic resources. Thus, the importance of research stems from the necessity to implement effective scientific methods that help reduce the cost of feed of broiler farms and achieve possible maximum profit.

Purpose of the Research

The research aims at shedding light on the efficiency of utilizing linear mathematical programming for reducing the cost of feed of broiler farms. ***This purpose is achieved through:***

1. Analyzing the most important financial evaluation indicators for broiler farming projects in Swaida governorate.
2. Proposing the optimal feed mix that decreases costs, taking into consideration the constraints of the available feed resources.
3. Analyzing the impact of the proposed feed mix on financial evaluation indicators.

Previous Studies

A number of studies tackled the topic of financial evaluation of poultry farming projects.

Balao, Abdul Hussein, and Abed (2018) revealed that producers in al-Muthanna governorate in Iraq were incompetent in using production inputs, especially pharmaceutical drugs. However, it was noted that their net cash flow, net farm income and farm work revenues amounted to 30461.82 IQD; 2877825 IQD; 28023.04 IQD respectively. Return of capital was found to be 1.057 and payback period was found to be 0.88 year. These are considered good indicators for the projects.

Darwish and Younes (2016) explored how the crisis in Syria affected broiler farming and production through comparing prices and costs before and after the crisis. Results showed that productive efficiency of broiler farming in Latakia was 1.85 in 2010 and 1.20 in 2014. Economic efficiency was found to be 1.72 in 2010 and 1.09 in 2014. Payback period was found to be 1.3 year in 2010 and 9.8 years in 2014.

Jado (2013) revealed that the most important production inputs that impact Broiler production in Egypt are the number of chicks, amount of feed, number of hours of human labor, and number of dead chicks. These variables were proved to be significant. The average net revenues for the sample was found to be 2,178.43 EGP/ton. Al-Aboudi's (2014) study used the linear programming method to identify the optimal feed. The price of one ton of the feed obtained by the mathematical programming was 116,861 IQD less than the low-quality standard feed sold at the local market.

Nath and Ashok (2014), showed the optimal solution of the linear programming model provides feed mix lower in costs than the current feed. The researchers developed a feed mix composed of 22.98 kg of rice bran, 3.96 kg of wheat bran, 15.32 kg of fish meat, and 57.72 kg of sesame seeds. All of these ingredients constituted 100 kg of feed which contained the minimum requirements of macronutrients. The 100 kg cost was estimated to be 1,426.57 INR.

Al-Masad, al-Tahat, and al-Sharafat (2011), using linear programming model, revealed different feed mixes used in the diet of egg laying chicken in Jordan in addition to the present market prices and ingredients. It was noted that the cost of one portion of feed in all stages was 25-45 JD less per ton than the standard feed mix sold at the market.

Al-Deseit (2009), showed that the optimal feed mix, obtained by linear programming model, which costs the minimum, was composed of 68% corn, 25.07% soy beans, 4% wheat bran, 0.5% fish powder, 0.5% calcium diphosphate, 0.1% lysine, 0.32% methionine, 0.3% limestone, and 0.3% salt, in addition to soybean oil, vitamins and minerals.

Methodology

1. Data: The study relied on preliminary data through field visits to breeders and the official institutions responsible for this sector to collect data on production costs and current agricultural prices. The data was collected through a questionnaire that addressed costs, productions and technical issues for the production season of 2018 in Swaida, Syria.

2. Sample selection: The sample included 104 broiler farmers in Swaida, Syria. The sample size was calculated according to the following equation (Glenn, 1992; Yamane, 1967):

$$n = \frac{N}{1 + N(e)^2}$$

Where:

N: Size of the study population, 210 broiler farms (Central Agr Extension, 2016).

e: Precision level, ±7%.

n: Sample size

3. Statistical analysis software: IBM SPSS Statistics 23 and Excel Solver were used to process and analyze the data in order to solve optimization problems in mathematical programming.

4. Statistical analysis method: The study adopted a number of methods of descriptive statistics such as arithmetic mean and graphs, in addition to the following:

♦ Financial analysis: Through using a number of evaluation indicators (Atieh, 2008; Al-Thenyian &Sultan, 1993; Al-Atwan &al-Homsi, 2011), as follows:

- Net income= gross revenues- gross expenses
- Operating ratio= gross operating expense/net sales
- Profitability of invested SYP: (average of net annual income/project's average expenses) * 100%
- Net Profit margin= Gross Product – variable expenses
- Revenues to expenses ratio
- The break-even point= fixed costs/(total sales revenues-variable expenses) * 100
- Variable assets turnover rate= gross domestic production/value of variable expenses
- Turnover time of variable assets= 365/ variable assets turnover

♦ Quantitative Analysis for Management: Using one of the Operations Research methods, which is linear programming. It is categorized under Decision Science, which has different common models. It is used to show the optimal use of production activities in light of the available resources and potentials. In other words, it is used for solving problems through finding optimal combinations of activities in order to achieve one of the following targets: maximization or minimization (Benjamin, 1985; Beneke, 1982&; Hazell & Norton, 1986). Linear programming is expressed as follows (maximization or minimization):

$$(\text{maximization})\text{or } (\text{minimization})\ z = \sum_{j=1}^{n} c_j x_j$$

Subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \geq\leq b_i \quad \text{for} \quad i = 1,2,\dots\dots,m$$

$$x_j \geq 0 \qquad \text{for} \quad j = 1,2,\dots\dots,n$$

Z:	Objective function	bi:	Available resources
C:	Coefficients of the objective function	n:	Number of activities
aij:	Coefficient Constraints	m:	Number of constraints
Xj	Activities (nominal variables)	Xj ≥ 0:	Non-negativity condition

Results and Discussion:

First: Economic Evaluation of broiler Farming Projects in Swaida:

1.1 Calculating total expenses:

The analysis of the questionnaire that was distributed to the sample of the study revealed that the expenses of producing 1kg of chicken meat is calculated, and the average expenses of five annual production cycles (2 summer cycles and 3 winter cycles) is calculated, noting that the average production cycle, starting from chicks rearing till marketing, lasts 45 days. The sum of fixed annual expenses were found to be 1,413,046.37 SYP for an average-sized farm, 720 m², that has an average number of chickens of 6478 chickens in summer cycle and 6541 chickens in winter cycle. Labor costs account for 74.15% of the fixed annual expenses, followed by the farm's rent of 23.30%. The fixed annual expenses for one production cycle amounted to 282,609.27 SYP per farm as detailed inTable1.

Table 1:

Average of fixed annual expenses for broiler farms according to the sample of the study

Item	Value SYP	Percentage %
1.Annual Labor Costs	1,047,805.98	74.15
2.Rent	329,230.77	23.3
3.License Fees	29,600.96	2.09
4.Income Tax (Finance)	1,403.85	0.1
5.Service Fees (Municipality)	639.42	0.05
6.Fees of Union's Supervision	1,403.85	0.1
7.Buildings and Land Tax	2,961.54	0.21
Total Fixed Annual Expenses	1,413,046.37	100
Total Fixed Annual Expenses per Production Cycle per Farm	282,609.27	

Source: Analysis of the questionnaire

Meanwhile, the average variable expenses for the summer production cycle amounted to 8,093,997.49 SYP per farm, and the average variable expenses for the winter production cycle amounted to 9,052,893 SYP per farm as detailed in Table 2.

Table 2:

The average variable expenses for the production cycle of broiler farms according to the sample of the study

Item	Summer Production Cycle		Winter Production Cycle	
	Value SYP	Percentage %	Value SYP	Percentage %
Chicks	1,524,139.42	18.83	1,656,163	18.29
Bedding	173,050.48	2.14	227,096.2	2.51
Water	94,721.15	1.17	100,701	1.11
Coal	226,130.77	2.79	820,873.1	9.07
Electricity	119,305.29	1.47	172,430.3	1.9
drugs and Vaccine	386,464.42	4.77	415,422.1	4.59
Feed	5,550,820.57	68.58	5,640,842	62.31
Cleaning and Disinfecting Substances	19,365.38	0.24	19,365.38	0.21
Total	8,093,997.49	100	9,052,893	100

Source: Analysis of the questionnaire

Table 3 shows the details of both variable and fixed total expenses. The analysis of the table reveals that variable expenses account for 97% of gross expenses in both summer and winter cycles. The total expenses for one chicken were found to be 1,441.87 SYP in summer, 1,568.79 SYP in winter, while the cost of producing 1kg of chicken meat was found to be 776.11 SYP in summer, and 782.57 SYP in winter.

Table 3:

Gross expenses for both summer and winter production cycles

Expenses	Summer Production Cycle		Winter Production Cycle	
	Value SYP	Percentage %	Value SYP	Percentage %
Variable Expenses SYP/Farm	8,093,997.49	96.63	9,052,893.16	96.95
Fixed Expenses SYP/Farm	282,609.27	3.37	282,609.27	3.03
Gross Expenses SYP/Farm	8,376,606.76	100	9,335,502.44	100
Number of Chicks	6,478		6,541	
number of deaths	668		590	
*Actual number of chicks	5,810		5,951	
Cost of One Chicken	1,441.87		1,568.79	
Amount of Meat in Ton	10.79		11.93	
Amount of Meat in Kg	10,793.08		11,929.33	
Cost of Producing 1 Kg of Meat	776.11		782.57	

Source: Analysis of the questionnaire

*: Actual number of chicks = total number of chicks - number of deaths

1.2 relative importance of variable expenses items:

The analysis of both summer and winter cycles' items, shows that feed expenses came first in terms of relative importance of broiler farms' variable production expenses in the governorate of Swaida, accounting for 62% of gross variable expenses in summer cycle and 69% in winter cycle. Meanwhile, expenses for purchase of chicks account for 18.19% of the gross variable expenses, while healthcare costs, such as vaccine and drugs, account for 5% of gross variable expenses in both summer and winter cycles. The costs of coal, which is used in heating, constitute 9% of the gross variable expenses in winter and only 3% of the gross variable expenses in summer.

1.3 Revenues and financial evaluation indicators:

Revenues included both main revenue from meat production and secondary revenue from by-products (poultry litters). Table 4 shows that the total revenue in the production cycle generated from the main product, meat, amounted to 8,361,202 SYP per farm. The main product's materiality constituted 99% of the gross revenues, while the total revenues from the sale of remnants amounted to 50,942.3 SYP per farm according to the study sample. Moreover, it was found within the sample that broiler farms' projects in the governorate of Swaida did not show a real economic feasibility according to all of the economic indicators as demonstrated by the following marginal values. First, the positive value of both the net income indicator, 35,537.47 SYP per farm, and the gross margin, 318,146.7 SYP per farm per production cycle. Second, the ratio of revenues to costs was found to be 1.004%, where the higher the ratio is than 1%, the more successful the project is. Third, operating ratio was found to be 0.996%, where the lower the ratio is than 1%,the more economically acceptable the project is. Last, the profitability of the invested

SY Preached 0.42% as shown in Table 4.

The financial evaluation indicators showed that these projects were not feasible for winter operating cycles and appeared with particularly negative values: net income, gross margin, and revenue on sales ratio. This is due to the fact that the projects afford, in addition to all their operating costs, an increase in the heating costs due to the high fuel prices, the high prices of chicks, in addition to the high consumption of medicines and vaccines in the winter cycles, as a result of the chances of the spread of pandemic diseases, all with relative stability at the sale prices of broilers. Referring to Table 2, and by comparing the details of the costs of the production process inputs, the difference between the variable costs for the summer and winter operating cycles is clear.

Table 4.

Revenues and the financial assessment indicators on the examined sample

Indicators	Summer Production Cycle	Winter Production Cycle
Total revenue from meat	8,361,202	7,606,063
Total revenue from poultry litters	50,942.3	102,653.9
Sum	8,412,144	7,708,716
Net income (net revenues of the farm)	35,537.47	-1,626,786
Operation rate	0.996	1.21
The profitability of invested Syrian Pound (Lira)	0.42	-17.4
Gross margin	318,146.7	-1,344,177
Revenues rate to costs	1.004	0.83
Break point	0.89	-0.21
The average of variable asset turnover	1.039	0.85
The timeframe of variable asset	351.2	428.65
Return on sales ratio	0.42	-21.1

Source: Analysis of the questionnaire

Second: The Mathematical Formula of the Linear Programming Model of the Optimal Feed Mix

This section deals with the study and analysis of the mathematical linear programming model of the optimal feed mix in the event of introducing any available feed component. This is accomplished through the study of the Starting ration, then the study of the Final ration, provided that the proposed feed mixes achieve the minimum and maximum limits of the required food components. (see annexes 1 & 2). The nutrition model will be adopted following two periods where the difference will be noticed in the amount of protein and energy that are needed to be available in the feed mix. The starting feed aged from one day- 4 weeks and had the energy of 3200 k cal ME/ kg of feed and 23% protein, while the final feed aged from 4 weeks was used for marketing, with 3200 k cal ME/ kg feed energy and 19% protein (Al-Rabee'i, 2013).

2.1. The linear mathematical analysis of the feed mix:

The linear mathematical programming model used to produce the optimal broiler chicken consists of;

A. Objective function: to minimize the cost of the bush feed mix to the minimum level, as follows;

$$\min z = 165x1 + 125x2 + 127x3 + 250x4 + 70x5 + 200x6 + 280x7 + 285x8 + 200x9 + 500x10 + 300x11 + 350x12 + 300x13 + 250x14 + 550x15 + 233.2x16 + 792x17 + 1496x18 + 50x19 + 1980x20$$

B. Constraints: These are the nutrition values that should be available in the bush.

	Constraints	Constraints Equations
1	All ingredients	$X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 + X10 + X11 + X12 + X13 + X14 + X15 + X16 + X17 + 1X18 + X19 + X20 = 1000$
2	Barley maximum level	$X2 \leq 250$
3	Bran maximum level	$X5 \leq 100$
4	Grains maximum level	$X1 + X2 + X3 + X4 + X5 \leq 500$
5	legumes maximum level	$X13 + X14 \leq 100$
6	Corn oil maximum level	$X15 \leq 30$

	Constraints	Constraints Equations
7	Salt maximum level	$X19 \le 3.5$
8	Salt & vitamins maximum level	$X20 \le 3$
9	Fats maximum level	$2.5X1 + 1.8X2 + 3.8X3 + 2.9X4 + 3X5 + 2.5X6 + 0.8X7 + X8 + 2.9X9 + 2.8X10 + 10X11 + 10X12 + 95X15 \le 7000$
10	Humidity maximum level	$11X1 + 11X2 + 12X3 + 11X4 + 11X5 + 9X6 + 10.4x7 + 10x8 + 7x9 + 10x10 + 8x11 + 5x12 \le 10000$
11	Fibers maximum level	$3X1 + 5.5X2 + 2.2X3 + 2X4 + 11X5 + 1.3X6 + 7X7 + 3.9X8 + 5X9 + 14X10 + X11 + 2X12 \le 7000$
12	Ash maximum level	$1.6X1 + 2.4X2 + 1.8X3 + 1.7X4 + 6.1X5 + 2X6 + 5.7X7 + 5.6X8 + 9.3X9 + 7.1X10 + 21.7X11 + 71.8X12 \le 5000$
13	Phosphorus maximum level	$0.31X1 + 0.36X2 + 0.28X3 + 0.13X4 + 1.15X5 + 0.19X6 + 0.65X7 + 0.62X8 + 0.16X9 + 0.42X10 + 2.95X11 + 14X12 + 0.18X13 + 0.11X14 + 18.7X16 \le 1000$
14	Calcium maximum level	$0.05X1 + 0.03X2 + 0.02X3 + 0.04X4 + 0.14X5 + 0.29X7 + 0.27X8 + 0.38X9 + 2.02X10 + 5.02X11 + 30X12 + 0.2X13 + 0.52X14 + 22X16 \le 1500$
15	Sodium maximum level	$0.07X1 + 0.02X2 + 0.01X3 + 0.01X4 + 0.3X5 + 0.03X6 + 0.24X7 + 0.34X8 + 0.3X10 + 0.46X12 \le 250$
17	Lysine maximum level	$0.39X1 + 0.4X2 + 0.26X3 + 0.25X4 + 0.61X5 + 1.29X6 + 2.69X7 + 2.69X8 + 1.73X9 + 1.09X10 + 4.83X11 + 0.87X12 + 1.34X13 + 1.73X14 + 100X17 \le 1400$
18	Methionine maximum level	$0.26X1 + 0.18X2 + 0.18X3 + 0.35X4 + 0.23X5 + 2.79X6 + 0.62X7 + 0.67X8 + 2.22X9 + 1.86X10 + 2.32X11 + 0.29X12 + 0.59X13 + 0.41X14 + 100X18 \le 600$
19	Di calcium phosphate maximum level	$X16 \le 20$
20	Corn oil minimum level	$X15 \ge 20$
21	Legumes minimum level	$X13 + X14 \ge 30$
22	Salt minimum level	$X19 \ge 2.5$
23	Vitamins & salt minimum level	$X20 \le 3 \ge 2.5$
24	Fats minimum level	$2.5X1 + 1.8X2 + 3.8X3 + 2.9X4 + 3X5 + 2.5X6 + 0.8X7 + X8 + 2.9X9 + 2.8X10 + 10X11 + 10X12 + 95X15 \ge 4000$
25	Humidity minimum level	$11X1 + 11X2 + 12X3 + 11X4 + 11X5 + 9X6 + 10.4x7 + 10x8 + 7x9 + 10x10 + 8x11 + 5x12 \ge 5000$
26	Fibers minimum level	$3X1 + 5.5X2 + 2.2X3 + 2X4 + 11X5 + 1.3X6 + 7X7 + 3.9X8 + 5X9 + 14X10 + X11 + 2X12 \ge 3000$
27	Ash minimum level	$1.6X1 + 2.4X2 + 1.8X3 + 1.7X4 + 6.1X5 + 2X6 + 5.7X7 + 5.6X8 + 9.3X9 + 7.1X10 + 21.7X11 + 71.8X12 \ge 2000$
28	Phosphorus minimum level	$0.31X1 + 0.36X2 + 0.28X3 + 0.13X4 + 1.15X5 + 0.19X6 + 0.65X7 + 0.62X8 + 0.16X9 + 0.42X10 + 2.95X11 + 14X12 + 0.18X13 + 0.11X14 + 18.7X16 \ge 500$
29	Sodium minimum level	$0.07X1 + 0.02X2 + 0.01X3 + 0.01X4 + 0.3X5 + 0.03X6 + 0.24X7 + 0.34X8 + 0.3X10 + 0.46X12 \ge 100$
30	Lysine minimum level	$0.39X1 + 0.4X2 + 0.26X3 + 0.25X4 + 0.61X5 + 1.29X6 + 2.69X7 + 2.69X8 + 1.73X9 + 1.09X10 + 4.83X11 + 0.87X12 + 1.34X13 + 1.73X14 + 100X17 \ge 800$
31	Methionine minimum level	$0.26X1 + 0.18X2 + 0.18X3 + 0.35X4 + 0.23X5 + 2.79X6 + 0.62X7 + 0.67X8 + 2.22X9 + 1.86X10 + 2.32X11 + 0.29X12 + 0.59X13 + 0.41X14 + 100X18 \ge 300$
32	Dicalcium phosphate minimum level	$X16 \ge 10$
33	Non negative entry	$X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, X13, X14, X15, X16, X17, X18, X19, X20 \ge 0$

However, the starting and final mix differ from each other in the value of protein and energy, thus the constraint identified between the two bush feed mix is the ratio of energy to protein and so the constraint entryis as follows:

Starting	minimum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \ge 139000$
	maximum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \le 139130$
Final	minimum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \ge 168000$
	maximum	$271.3043X1 + 240X2 + 418.75X3 + 281.58X4 + 82.80X5 + 62.66X6 + 50.6818X7 + 50.309X8 + 41.79X9 + 54.29X10 + 45.8X11 + 115.53X12 + 132.5X13 + 112.6383X14 \le 168421$

2.2. Application of linear programming model:

The percentage of the main ingredients of the optimal mix. Table 5 shows the quantities of the main ingredients of the proposed feed mix, and the proportion of each in the optimal mix with the cost, as follows;

- ♦ The starter: the amount of barley was the highest with respect to the ingredients of the mix as it reached 250kg, 25% of the mix, followed by sunflower meal which amounted to 145.61kg, around 14.56 % of the mix, then soybean meal which amounted to 140.8 kg, around 14.08% of the mix. As for wheat, corn, bran, lentil, soybean meal and corn oil, all amounted to 48%. The quantities of each in the mix were as follows respectively; 133.3, 16.6, 100, 100, 63.8 and 23.7 kg at about 13.3%, 1.66%, 10%, 10%, 6.38% and 2.37%. For feed supplements (dicalcium, food salt, as well as vitamins and mineral salts), they were in the order of 20, 3.5 and 2.5 kg at 2%, 0.35% and 0.25% respectively.
- ♦ The finisher: The amount of yellow corn amounted to 203.282 kg around 20.33% which is the highest value in the mix, then barley at 196.71 kg with 19.67% of the mix, then sunflower meal and soybean meal 48% which amounted to 148 kg of the mix each reached 14.8%. As for bran, lentil, soybean meal and corn oil, they amounted to 44%, as follows 100, 100, 56.95, 20.5 kg(10%, 10%, 5.65% and 2.05% respectively). As for the supplementary feed (dicalcium, food salt, vitamins and mineral salts), they were in the order of 20, 3.5, 2.5 with 2%, 0.35%, 0.25% respectively.

Table 5.

Results of using linear mathematical programming model in the proposed feed mix.

Ingredients	*Price SYP	Amount		Amount in percent		Cost	
		Final	Starting	Final	Starting	Final	Starting
Wheat	165	0	133.34	0	13.33	0	22,000.95
Barley	125	196.72	250.00	19.67	25.00	24,589.78	31,250
Corn	127	203.28	16.66	20.33	1.67	25,816.78	2,115.94
Sorghum	250	0	0	0	0	0	0
Coarse bran	70	100	100	10	10	7,000	7,000
Corn gluten 60%	200	0	0	0	0	0	0
Soybean meal 44%	280	56.95	140.84	5.70	14.08	15,946.82	39,434.92
Soybean meal 48%	285	148.13	63.82	14.81	6.38	42,216.98	18,188.27
Sunflower meal	200	148.40	145.61	14.84	14.56	29,679.48	29,122.01
Sesame meal	500	0	0	0	0	0	0
Fish meal	300	0	0	0	0	0	0
Bone meal	350	0	0	0	0	0	0
Chickpeas	300	0	0	0	0	0	0
Lentil	250	100	100	10	10	25,000	25,000
Corn oil	550	20.52	23.73	2.05	2.37	11,285.95	13,052.84
Dicalcium phosphate	233.20	20	20	2	2	4,664	4,664
Lysine	792	0	0	0	0	0	0
Methionine	1496	0	0	0	0	0	0
Salt	50	3.50	3.50	0.35	0.35	175	175
Vitamins and salt	1980	2.50	2.50	0.25	0.25	4950	4950
Total		1000	1000	100	100	191,324.80	196,953.93

Reference: These calculations were obtained using excel solver.

3.2. The cost of the optimal feed mix:

Tables 5 & 6 show the cost of one ton of feed according to the results of the applied model and it was compared with breeders' cost of one ton of feed. The gross cost of one ton of the proposed starting feed mix when applying the linear programming model was about 196,953.93 SYP per ton. While the average price per ton for the starter feed mix used by the breeders was about 235,000 SYP. There is a decrease in cost about 38,046.066 SYP per ton, i.e. the cost decreased by about 16.1988%.

In the other hand, the gross cost per ton of the proposed final mix through the application of the linear programming model is about 191,324.8 SYP per ton, while the average price per ton for the final feed mix used by the breeders was about 230,000 SYP, i.e. there is a decrease in cost about 38,675.2 per ton, as the cost decreased by about 16.8%.

Table 6:

The cost per ton of the mix obtained from the linear programming model and the mix used by the breeders

The Feed Mix Cost	Starting	Final
Used by the breeders SYP/ton	235,000	230,000
The mix obtained by using the linear programming model	196,953.934	191,324.8
The difference between the two mix	38,046.066	38,675.2
The difference in percent	16.1898	16.8

Source: These results were calculated based on the previous table, from the questionnaire

Third: The Impact of Feed Cost Decreased by 16% on the Indicators of the Financial Evaluation

The results of the study showed that the rearing projects of broilers chicken in the governorate of Sweida with respect to the sample did not show any actual economic feasibility in terms of all economic indicators (summer production cycle), as what the boundary values of their indicators have shown. On the other hand, indicators showed the infeasibility of these projects during the winter production cycle of the sample. The results of applying the linear programming model revealed that the total cost per ton of the starting feed was about 196,953,934 SYP, i.e. the cost per one ton decreased by approximately 16.1898%. The total cost per ton of the proposed final feed mix obtained by the application of the linear programming model amounted to about 191,324.8 SYP, thus reducing the cost per ton by about 16.8%. However, in this section, we will tackle the impact of feed cost decrease by 16% (mean) on the computerized financial evaluation indicators of the sample, through studying the impact of feed cost decrease on the variable costs and the stability of the fixed computerized variables of the sample, in addition to the macro fixed revenues (from meat and remnants).

3.1.The impact of feed cost decrease by 16% on the indicators of the financial evaluation on the variable costs:

Table 7 shows that during the summer production cycle when comparing the ratio of the feed cost vis-à-vie the variable costs, it was found that it decreased from 68.58% to 64.71%, and from 62.31% to 58.14% during the winter production cycle. However. The cost of rearing chicks increased from 18.83% to 21.15% from the variable costs during the summer production cycle, and from 18.29% to 23.32% during the winter production cycle. Moreover, the cost of the variable costs has decreased from 8,093,997.5 SYP of the chicken farm during the summer production cycle to 7,205,866 SYP, and the cost also decreased from 9,052,893.1 SYP to 8,150,358.4 of the chicken farm during winter production cycle.

Table 7.

Variable costs for both summer and winter production cycle, after the cost of the obtained feed mix by using the linear program has decreased by 16%

The Cost of the Farm During the Cycle in SYP	The obtained feed mix by using the linear program			
	Summer Cycle		Winter Cycle	
	Value	%	Value	%
1. Chicks	1,524,139	21.15	1,656,163	20.32

The Cost of the Farm During the Cycle in SYP	The obtained feed mix by using the linear program			
	Summer Cycle		Winter Cycle	
	Value	%	Value	%
2. Bedding	173,050.5	2.4	227,096.2	2.79
3. Water	94,721.15	1.31	100,701	1.24
4. Coal	226,130.8	3.14	820,873.1	10.07
5. Electricity	119,305.3	1.66	172,430.3	2.12
6. Drugs and vaccines	386,464.4	5.36	415,422.1	5.1
7. Feed	4,662,689	64.71	4,738,307.3	58.14
8. Sterilizing and cleaning materials	19,365.38	0.27	19,365.38	0.24
The total of variable costs	7,205,866	100	8,150,358.4	100

Source: Computed based on the questionnaire data and the results of the proposed linear programming model.

3.2.The impact of feed cost decrease by 16% on the indicators of financial evaluation:

By analyzing table 8, we notice that the indicators of the financial evaluation with respect to the sample has improved. The positive value for each net income index is 35,537.47 SYP/farm; while the gross margin is 318,146.7 SYP/farm per one production cycle of the normal feed mix which has increased to 921,477.99 while the gross margin amounted to 1,206,278.42 SYP/farm to the mix obtained by using the linear programming model. However, the value of the revenues ratio to costs has increased to more than 1% from 1.004% to 1.123% and this shows that the project is more profitable when it jumps above 1%. Moreover, the operation ratio has decreased from 0.996% to 0.890% and this indicates that the project is feasible. Nevertheless, the profitability of the invested pound rose from 0.42% to 12.302%. Moreover, the ratio of return on sales increased from 0.42% to 10.954%, and the turnover of variable assets decreased from 351.2 to 312.66 days as shown in table 8.

Although the financial indicators in winter cycles when using mixes extracted by mathematical linear programming models were better, there were clear losses as the financial indicators did not show the economic feasibility of these projects. This is due to several main factors imposed by the production process during the winter cycles, ***the most important of which are:***

- High heating costs (hydrocarbons or coal).
- High mortality rates due to prevailing weather factors.
- High prices of chickens during winter cycles.

Table 8.

Impact of the feed cost decrease by 16% on the computerized indicators of the financial evaluation of the sample.

Indicator	Summer Cycle		Winter Cycle	
	Normal mix	Linear programming mix	Normal mix	Linear programming mix
Net income (of the farm)	35,537.47	921,477.99	-1,626,786	-726,442.056
2. Operation ratio	0.996	0.890	1.21	1.094
3. The profitability of the invested Lira	0.42	12.302	-17.4	-8.612
4. Gross margin	318,146.7	1,206,278.04	-1,344,177	-441,642.014
5. The ratio of revenues to costs	1.004	1.123	0.83	0.914
6. Break point	0.89	0.236	-0.21	-0.645
7. The average of variable assets	1.039	1.167	0.85	0.946
8. The cycle duration of the variable assets	351.2	312.66	428.65	385.911
9. Return on sales ratio	0.42	10.954	-21.1	-9.424

Source: Computed based on the questionnaire data and the results of the proposed linear programming mode

Conclusion

The results of applying the linear programming model showed the following:

1. For the starter: The amount of barley reached the highest value of the mix ingredient. It amounted to 250kg, i.e. 25% of the mix, then sunflower meal which reached 145.61 kg by about 14.56% of the mix, followed by soybean meal 44%, 140.8 kg, i.e. 14.08% of the mix. The total cost per ton of the proposed starting mix when applying the linear programming model amounted to about 196,953,934 SYP, i.e. the cost decreased by approximately 16.1988%.

2. For the finisher: The amount of yellow corn reached the highest value of the mix ingredients. It amounted to 203.282 kg, i.e. 20.3% of the mix, then barley which reached 196.71 kg, i.e. 19.67% of the mix, followed by sunflower meal and soybean meal which amounted to 48%, each for 148 kg, i.e. 14.8%. However, the total cost of one ton of the final feed that was obtained using the linear programming model amounted to 191,324.8 SYP, i.e. which decreased by 16.8% approximately.

3. Through analyzing and studying the impact of feed cost decrease by 16% on the computed financial indicators of the sample, it is noted that the value of the variable costs has decreased to 7,206,866 SYP/farm during the summer production cycle and to 8,150,358.4 SYP/farm during the winter production cycle.

4. The indicators of the financial evaluations has improved at the sample level, as the value of the gross and net margin has increased to 921,477.999 and 1,206,278.042 SYP/farm of the obtained mix by using the linear programming model. The ratio of revenues to costs jumped above 1% to reach 1.123 %, and the operation cost increased to 0.890% whereas the profitability of the invested Lira increased to 12.302%. The net profit margin increased to 10.954 % and the turnover of the variable assets decreased to 312.66 days.

5. The results obtained showed that they are consistent with what was presented in the research of studies that used the linear programming methodology to determine optimal feeds; The use of programming models in the selection of feed mixtures reduced the cost of feed and this is shown in Al-Aboudi (2014), Nath & Ashok (2014), Almasad et.al.(2011) and Al-Deseit (2009).

Recommendations

1. The possibility to apply the linear programming model in the poultry sector, in order to identify the optimal feed mix at the lowest cost. Provide a model of the mix which fits the price fluctuation and the provision of the feed ingredients at the lowest cost.

2. The availability of different feed ingredients that provide nutrients and the needed conditions in the composition of the feed mix, which can be replaced partially in different quantities and percentages, or can be replaced in full, in the event of high prices, or lack of availability of such materials.

3. The study recommends the application of the linear programming model in identifying the optimal and civil mix and its cost in the poultry sector, as well as to expand the introduction of other feed ingredients in the mix if available.

4. The need for applying the proposed mixture in reality, to review its nutritional suitability for broilers.

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Annexes

Annex 1:

The Chemical Analysis of the Feed Ingredients in the Proposed Mix

symbol	Ingredient	*Price SYP	Calories c	Protein %	Fats %	Fibers %	Ca %	P %	Na %	Lysine %	Methionine %
x1	Wheat	165	3120	11.5	2.5	3	0.05	0.31	0.07	0.39	0.26
x2	Barely	125	2640	11	1.8	5.5	0.03	0.36	0.02	0.4	0.18
x3	Yellow corn	127	3350	8	3.8	2.2	0.02	0.28	0.01	0.26	0.18
x4	White corn	250	3210	11.4	2.9	2	0.04	0.13	0.01	0.25	0.35
x5	Coarse bran	70	1300	15.7	3	11	0.14	1.15	0.3	0.61	0.23
x6	Yellow corn gluten 60%	200	3720	62	2.5	1.3	0	0.19	0.03	1.29	2.79
x7	soybean meal 44%	280	2230	44	0.8	7	0.29	0.65	0.24	2.69	0.62
x8	Soybean meal 48%	285	2440	48.5	1	3.9	0.27	0.62	0.34	2.69	0.67
x9	Sunflower meal	200	2320	45	2.9	5	0.38	0.16	0	1.73	2.22
x10	Sesame meal	500	2210	43.5	2.8	14	2.02	0.42	0.3	1.09	1.86

symbol	Ingredient	*Price SYP	Calories c	Protein %	Fats %	Fibers %	Ca %	P %	Na %	Lysine %	Methionine %
x11	Fish powder	300	3190	72.3	10	1	5.02	2.95	0	4.83	2.32
x12	Bones powder	350	2150	50.4	10	2	30	14	0.46	0.87	0.29
x13	Chickpeas	300	2756	20.8	-	-	0.2	0.18	0	1.34	0.59
x14	Lentil	250	2647	23.5	-	-	0.52	0.11	0	1.73	0.41
x15	Corn oil	550	8800	-	95	-	-	-	-	-	-
x16	deCalcium PhoSYPhate	233.2	-	-	-	-	22	18.7	-	-	-
x17	Lysine	792	-	-	-	-	-	-	-	100	-
x18	Methionine	1496	-	-	-	-	-	-	-	-	100
X19	Salt	50	-	-	-	-	-	-	-	-	-
x20	Vitamins and salt	1980	-	-	-	-	-	-	-	-	-

Source: Al-Aboudi (2014), NRC (1994), Al-Ribat & Hassan (1986) (*): prices for 2018.

Annex2:

Maximum and Minimum Limits of the Most Important Nutrition Elements

Ingredients	Maximum limit	Minimum limit
Fats	%7	%4
Humidity	%10	%5
Fibers	%7	%3
Ash	%5	%2
Phosphorus	%0.1	%0.5
Calcium	%1.5	%0.7
Sodium	%0.25	%0.1
Lysine	1.4	%0.8
Methionine	%0.6	%0.3
Phosphorus/ Calcium	%2	%1.5
Vegetable oils	%3	%2
legumes	%10	%0.03
Grains	%50	-
Salt Kg/Tons	3.5	2.5
Vitamins and Salts Kg/Tons	3	2.5
Di calcium phosphate Kg/ Tons	20	10
Barley	%25	-
Bran	%10	-

Source: Al-Kassar (2012), Al-Rabee›i(2013)

Reliability and Failure Probability Functions of the Consecutive-k-out-of-m-from-n: F System with Multiple Failure Criteria

اقتران موثوقية و اقتران احتمال فشل النظام التتابعي k-out-of-m-from-n: F متعدد معايير الفشل

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Abstract:

The consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria consists of n sequentially ordered components (K= (k_1, k_2,..., k_H), m = (m_1, m_2,..., m_H)). The system fails if among any m_1, m_2,..., m_H consecutive components there are at least k_1, k_2,..., k_H components in the failed state. In this paper, the ordinary consecutive-*k*-out-of-*m*-from-*n*: F system played a pivotal role in achieving the reliability and failure probability functions of the consecutive-**k**-out-of-**m**-from-*n*: F linear and circular system with multiple failure criteria. We proved that the failure states of the multiple failure criteria system is a union of all failure state of the consecutive-k_i-out-of-m_i-from-*n*: F system, while the functioning state is an intersection of the functioning states of the consecutive-k_i-out-of-m_i-from-*n*: F system for $i \in \{1,2,....H\}$. The maximum number of failed components of the functioning consecutive **k**-out-of-**m**-from-*n*: F system with multiple failure criteria is computed.

Keywords: Consecutive *k*-out-of-*m*-from-*n*: F system, Reliability function, Failure probability function

ملخص:

يتكون النظام التتابعي k-out-of-m-from-n: F متعدد معايير الفشل من n من المكونات أو الأجزاء، والذي يفشل إذا حدث انه خلال أي من m_1, m_2,..., m_H المكونات المتتابعة يفشل خلالها على الأقل k_1, k_2,..., k_H عدد من المكونات.

في هذا البحث تم استنتاج اقتران الكثافة الاحتمالي للموثوقية والفشل لهذا النظام من خلال استخدام طبيعة ومكونات النظام العادي ذو الشرط الوحيد k-out-of-m-from-n: F، فلقد أثبتنا أن حالات الفشل للنظام التتابعي متعدد معايير الفشل هو فعليا اتحاد لحالات الفشل للنظام التتابعي ذو الشرط الوحيد(k_i-out-of-m_i-from-*n*: F) ، أما حالات العمل للنظام التتابعي متعدد معايير الفشل فهي تقاطع حالات العمل للنظام التتابعي ذو الشرط الوحيد (k_i-out-of-m_i-from-*n*: F) ، خلال هذا كله، تم حساب العدد الأقصى للمكونات أو الأجزاء التي ممكن أن تفشل بحيث يبقى النظام ككل في حالة العمل.

الكلمات المفتاحية: النظام التتبعي ذو الشرط الوحيد، اقتران موثوقية ، احتمال فشل النظام التتبعي.

Notation

L(C):	Linear (circular)
i.i.d.:	Independent and identically distributed
I_j^i	$=\{i,i+1,...,j\}$ $1 \le i < j \le n$
$P(I_n^1)$:	The power set of I_n^1.
$X=\{x_1,x_2,...,x_j\}$:	A subset of I_n^1, such that $x_i < x_h$ for all $1 \le i < h \le j \le n$
f_n^t:	The composite function t times, where $f_n(x) = x \bmod_n + 1 : x \in I_n^1$
$d_X = (d_1^X, d_2^X, ..., d_j^X)$:	The rotations of the set $X=\{x_1,x_2,...,x_j\}$, such that $d_i^X \ge 1$ is the minimum integer number such that $f_n^{d_i^X}(x_i) = x_{i+1}$, for i=1,2,…, j-1, and $f_n^{d_j^X}(x_j) = x_1$, where $n = \sum_{i=1}^{j} d_i^X$.
$M_r^{L(C)} = (k_r - 1)\lceil n/m_r \rceil + s_r^{L(C)}$	where $s_r^C = \begin{cases} b_r - m_r + k_r - 1 & b_r \ge m_r - k_r + 1 \\ 0 & \text{otherwise} \end{cases}$ $s_r^L = \begin{cases} k_r - 1 & b_r \ge k_r - 1 \\ b_r & b_r < k_r - 1 \end{cases}$, and $b_r = n \bmod m_r$.
$d_X^t = (d_{j-t+1}^X, ..., d_j^X, d_1^X, ..., d_{j-t}^X)$ $t \in \mathbf{Z}$,	where $d_X^0 = d_X^j, d_X^{j+s} = d_X^s, t \le j$

$\overline{X}$: The complement of the set X.

$|X|$: The cardinality of the set X.

$\equiv, \sim$: Equivalence relations

$i \underset{j}{\oplus} r$ $= (i+r) \bmod j$, unless if $i+r = nj$ then $i \underset{j}{\oplus} r = j$, when $n \in \mathbf{Z}$

$p_i(q_i)$: The reliability (unreliability) of the i^{th} components

$R(X)(F(X)) = p_X = \prod_{i \in \overline{X}} p_i \prod_{j \in X} q_j$, the reliability (unreliability) of the set X.

$\Psi_{L(C)}^{k,m,n}\left(\Theta_{L(C)}^{k,m,n}\right)$: The collection of all failure (functioning) states of the consecutive-k-out-of-m-from-n: F linear (circular) system.

k,m: Vectors representing failure criteria in the system, ($\mathbf{k} = (k_1, k_2, ..., k_H)$, $\mathbf{m} = (m_1, m_2, ..., m_H)$)

$\Psi_{L(C)}^{\mathbf{k},\mathbf{m},n}\left(\Theta_{L(C)}^{\mathbf{k},\mathbf{m},n}\right)$: The collection of all failure (functioning) states of the consecutive-**k**-out-of-**m**-from-n: F linear (circular) system

p_n^s $= p(n,s) = p^{n-s} q^s$

$\overline{[n]}$: The greatest integer number of n.

1. INTRODUCTION

Over time, the requirements of people's life have become very complicated, requiring highly complex and sophisticated systems. Consequently, this urges the engineers to insure that these systems will perform the required functions. In this context, they developed theorems for such systems, and applied available results for all type of systems, including system reliability, optimal system design, component reliability importance, and reliability bounds.

The consecutive-k-out-of-m-from-n: F system model has interested many engineers since 1985. It is a generalization of the famous consecutive-k-out-of-n: F system which had been used in the telecommunication networks, spacecraft relay stations, vacuum systems in accelerators, oil pipeline systems, photographing nuclear accelerators, microwave stations of a telecom network, etc. Kontoleon (1980) was the first person to introduce the system under the name "r-successive-out-of-n:F system", then Chiang & Niu (1981) created the name "consecutive k-out-of-n: system". Bollinger (1982) presented a direct combinatorial method for determining the system failure probability. Shanthikumar (1982) and Derman et al. (1982) provided a recursive algorithm to evaluate the reliability of the system. Bollinger (1986) introduced a simple and easily programmed algorithm for calculating a table of the coefficients for the failure probability polynomials, associated with the system where the components are i.i.d. Eryılmaz (2009) studied the reliability properties of the consecutive k-out-of-n systems when the components are arbitrarily dependent. Chao M. T, Lin G.D. (1984) and Fu & Hu (1987) studied the reliability of the consecutive k-out-of-n: F system using the Markov chain. Lambiris and Papastavridis (1985) and Nashwan (2015) introduced exact formulas for the reliability of the linear and circular system with i.i.d. components. Dăuş and Beiu (2015) computed the lower and upper bound of the system with a large number of components, and Gökdere (2016) provided a simple way for determining the system failure probability.

The consecutive-k-out-of-m-from-n: F system consists of n components. The components are connected linearly or circularly. The system fails if at least k failed components are included in any m consecutive components. Such a system model was applied in many applications, such as radar detection, quality control and inspection procedures. Tong (1985) was the first to mention the system, while Griffith (1986) introduced the system formally. Afterwards, many researchers studied the system's reliability, failure functions, reliability bounds, optimal system design, etc. Sfakianakis et al. (1992) provided explicit algorithms for the reliability of consecutive-k-out-of-m-from-n: F linear and circular system when the components are i.i.d. Papastavruds & Higsiyama et al. (1995), studied a special case when k=2 with unequal component probabilities. Malinowski & Preuss (1995, 1996) evaluated the reliability of the system with independent component which failure probability may be unequal. Habib et al. (2007) used the total probability theorem to evaluate the reliability of a special case of multi-state consecutive *k*-out-of-*r*-from-*n*: G system. Amirian et al. (2019) provided an algorithm for the exact reliability function of the consecutive k-out-of-r-from-n: F system.

Koutras (1993) provided upper & lower bounds for the reliability of a (linear or circular) consecutive-*k*-out-of-*m*-from-*n*: F system with unequal component failure probabilities. Habib et al. (2000) and Radwan et al. (2011) introduced new bounds for the reliability of the consecutive *k*-out-of-*r*-from-*n*: F system.

The linear consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria consists also of n connected linearly components. $\mathbf{k}$ and $\mathbf{m}$ are failure integer vector, $\mathbf{k}=\{k_r \mid 1\le r\le H\}$ and $\mathbf{m}=\{m_r \mid 1\le r\le H\}$, where $m_r \le m_{r+1}\le n$, and $k_r \le m_r$. The system fails if at least one group of m_r consecutive components exists in which at least k_r components are in a failed state, for any $1\le r\le H$. One can easily demonstrate that, for any r, if $k_r=1$, then it becomes a series system.

Actually Levitin (2004) generalized the linear consecutive-*k*-out-of-*r*-from-*n*: F system to the case of multiple failure criteria, and evaluated only the reliability of the system. He used an extended universal moment generating function, and introduced motivated examples as applications, such as the radar system, combat system and the heating system as shown in figure 1.

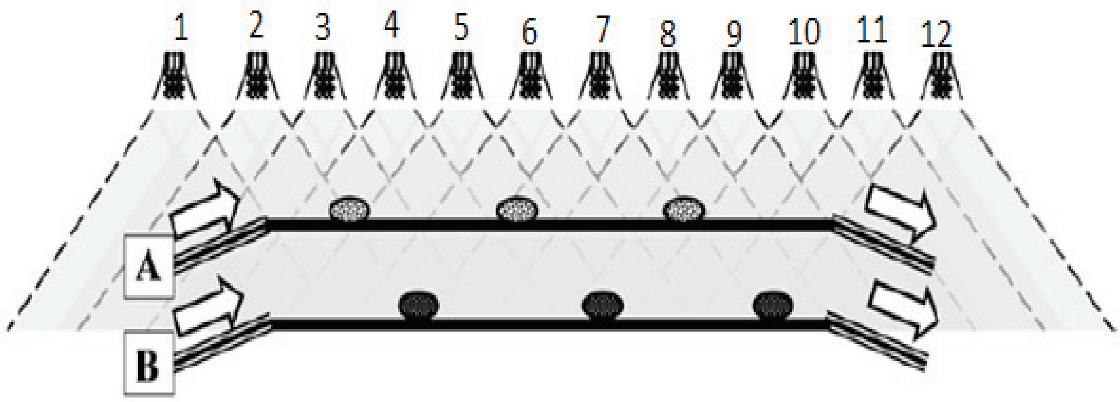

Fig. 1:
The heating system (The linear consecutive-(2,3)-out-of-(3,5)-from-12: F system).

The system consists of 12 heaters, which should provide a certain temperature along the 2 heating lines A and B. The temperature through the two lines at any point is determined by the cumulative effects of the 3 and 5 adjacent heaters, respectively. The heaters cannot provide a certain temperature, if at least 2 out of 3 consecutive heaters, or at least 3 out of 5 consecutive heaters are in the failure state, i.e. the whole system is in failure condition.

In this paper, we developed the classification technique of Nashwan (2018) for the ordinary consecutive-*k*-out-of-*m*-from-*n*: F system (one failure criteria) to compute the exact reliability and failure probability functions of the consecutive-*k*-out-of-*m*-from-*n*: F system with multiple failure criteria. We also developed some conditions to determine the failure and the working states of the system.

In the following section, we study the failure and the functioning states of the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria using the simple one failure criteria system properties (the circular consecutive-*k*-out-of-*m*-from-*n*: F system). This in turn paved the way to classify them again within the linear type in the third section. Moreover, we computed the maximum possible number of failure components whenever the system is in the functioning state. Finally, an algorithm to find the reliability and failure probability functions of the linear and circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria is obtained. Through all, the system and the components are satisfied by the following:

- The state of the component and the system are either "functioning" or "failed".
- All the components are mutually statistically independent.

2. The circular consecutive-*k*-out-of-*m*-from-*n*: F system with multiple failure criteria

Consider the components indices of the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria are denoted by I_n^1, $P(I_n^1)$ is the failure space of the components indices. The system is represented by the set $X=\{x_1,x_2,...,x_j\}\in P(I_n^1)$, which consists of all the indices of the failed components.

Fix $r\in I_H^1$, then X is a failure state of the system, if there is a m_r consecutive components (whether in the functioning or in the failure state), and among them k_r indices included in *X*, i.e. there is a k_r failed components from *X* among any m_r consecutive components. Moreover, if $Y\in P(I_n^1)$ such that $X\subseteq Y$, then *Y* is also a failure state. Actually, *X* is a failure state of the simple one criteria circular consecutive-k_r-out-of-m_r-from-*n*: F system.

Conversely, if X is a functioning state of the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria, if it does not hold any failure criteria of the failure vector , i.e. for all $r\in I_H^1$ X is a functioning state in the simple one criteria circular consecutive-k_r-out-of-m_r-from-*n*: F system. In this context, we claim the following:

Claim: $\Psi_C^{\mathbf{k},\mathbf{m},n}=\bigcup_{r=1}^{H}\Psi_C^{k_r,m_r,n}$, and $\Theta_C^{\mathbf{k},\mathbf{m},n}=\bigcap_{r=1}^{H}\Theta_C^{k_r,m_r,n}$.

Proof: If $X\in\Psi_C^{\mathbf{k},\mathbf{m},n}$, then *X* hold at least one failure criteria of the failure vectors, i.e. there exists $r\in I_H^1$ such that X contains at least k_r (indices) failed components among m_r consecutive components, which implies that, X is a failure state of the simple circular consecutive-k_r-out-of-m_r-from-n: F system, i.e. $X\in\Psi_C^{k_r,m_r,n}$, which means that $X\in\bigcup_{r=1}^{H}\Psi_C^{k_r,m_r,n}$. Conversely is trivial.

For the functioning states, if $X\in\Theta_C^{\mathbf{k},\mathbf{m},n}$, then it does not hold any criteria of the failure vectors, i.e. for all $r\in I_H^1$, $X\in\Theta_C^{k_r,m_r,n}$ which implies that $X\in\bigcap_{r=1}^{H}\Theta_C^{k_r,m_r,n}$. Conversely is trivial.

Again, fix any $r\in I_H^1$, Nashwan (2018) partition $P(I_n^1)$ of the consecutive-k_r-out-of-m_r-from-*n*: F linear (circular) system into finite pairwise disjoints classes on the form $[X]=\{f_n^\alpha(X):\alpha\in\mathbf{Z}\}$, where $f_n:I_n^1\to I_n^1$ is a bijection function, such that $f_n(x)=(x\bmod n)+1$ for any $x\in I_n^1$. He explained that, for any two states $X,Y\in P(I_n^1)$, $[X]=[Y]$ if there exists $t=1,2,...,j$ such that $d_Y=d_X^t$. Moreover, he classified $P(I_n^1)$ into two sub collections, $\Psi_{L(C)}^{k_r,m_r,n}$ and $\Theta_{L(C)}^{k_r,m_r,n}$, and computed $M_r^{L(C)}$, the maximum possible failed components, when the consecutive-k_r-out-of-m_r-from-*n*: F linear (circular) system is in the functioning state. For example, in the consecutive-3-from-4-out-of-9: F circular system, the set $X=\{1,2,4,5\}$, for simply $X=1245$, means that, the only failed components are the components with the indices 1,2,4, and 5. The class $[1245]=\{1245,2356,....,1349\}\in\Psi_C^{3,4,9}$, and $[1245]=[2389]$, since $d_{1245}=(1,2,1,5)=d_{2389}^2$, while $M^C=(3-1)\overline{\lceil 9/4\rceil}+0=2\times 2=4$. Moreover, $X=1245\in\Psi_C^{(3,k_2),(4,m_2),9}$ for any integer numbers k_2,m_2, where $k_2\le m_2\le 9$. The next lemma adds more details on the failure and the functioning states of the system.

Lemma 2.1: If the circular consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria is represented by $X=\{x_1,....,x_j\}\in P(\mathsf{I}_n^1)$ such that $j\ge k=\min_{1\le r\le H}\{k_r\}$, define $S_C^X(m_r)=\left\{S_i^X=\sum_{t=0}^{k_r-2}d_{i\oplus_j t}^X : i\in\mathsf{I}_j^1\right\}$, then X is a failed state, if there exists $(i,r)\in\mathsf{I}_j^1\times\mathsf{I}_H^1$ such that $S_i^X\prec m_r$,.

Proof: If there exists $(i,r)\in\mathsf{I}_j^1\times\mathsf{I}_H^1$, such that $S_i^X=\sum_{t=0}^{k_r-2}d_{i\oplus_j t}^X\prec m_r$; hence the total steps on the circle to walk through the k_r distinct failed components $\{x_i,x_{i\oplus_j 1},....,x_{i\oplus_j k_r-1}\}\subseteq X$ is less than m_r steps, i.e. k_r distinct failed components among m_r consecutive components, hence the system fails.

Lemma 2.2: For any two states $X,Y\in P(\mathsf{I}_n^1)$ represent the circular consecutive-k-out-of-m-from-n: F system with multiple failure criteria, such that $Y\in[X]$,

- ♦ If $X\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$, then $Y\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$.
- ♦ $R(Y)=F(Y)=p_{f_n^\alpha(X)}$ for some $\alpha\in\mathbf{Z}$.
- ♦ If the components are i.i.d., then $R(Y)=R(X)=p_n^{|X|}$ and $F(Y)=F(X)=p_n^{|X|}$.

Proof:

- ♦ If $X\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$, and $Y\in[X]$, then there exists $t\in\mathsf{I}_j^1$ such that $d_Y=d_X^t$, which implies that $S_C^X(m_r)=S_C^Y(m_r)$, i.e. $Y\in\Psi_C^{\mathbf{k},\mathbf{m},n}\left(\Theta_C^{\mathbf{k},\mathbf{m},n}\right)$.
- ♦ If $Y\in[X]$, then there exists $\alpha\in\mathbf{Z}$, such that $Y=f_n^\alpha(X)$, hence , $R(Y)=p_Y=p_{f_n^\alpha(X)}$. Also $F(Y)=p_Y=p_{f_n^\alpha(X)}$
- ♦ If the components are i.i.d., then $|X|=|Y|$, apply 2, $R(X)=p_n^{|X|}=p_n^{|Y|}=R(Y)$

Note: The reliability and the failure probability functions of the class $[X]$ are $\mathsf{R}[X]=\sum_{Z\in[X]}R(Z)=\sum_{Z\in[X]}p_Z$, and $\mathsf{F}[X]=\sum_{Z\in[X]}F(Z)=\sum_{Z\in[X]}p_Z$ respectively.

3. The linear consecutive-*k*-out-of-*m*-from-*n*: F system with multiple failure criteria

In this section, the procedure for the system reliability and failure evaluation is based on connecting the 1st and n components in the linear consecutive-**k**-out-of-**m**-from-*n*: F system, and treating the system as a circular type. However, this connection creates more failure states than that in the linear system, i.e. $\Psi_L^{\mathbf{k},\mathbf{m},n}\subseteq\Psi_C^{\mathbf{k},\mathbf{m},n}$ and $\Theta_L^{\mathbf{k},\mathbf{m},n}\supseteq\Theta_C^{\mathbf{k},\mathbf{m},n}$; hence our duty is to separate these extra failures states from $\Psi_C^{\mathbf{k},\mathbf{m},n}$ and add them to $\Theta_C^{\mathbf{k},\mathbf{m},n}$ to compute $\Theta_L^{\mathbf{k},\mathbf{m},n}$.

Lemma 3.1: If the linear consecutive-**k**-out-of-**m**-from -*n*: F system with multiple failure criteria is represented by the set $X=\{x_1,...,x_j\}\in P(\mathsf{I}_n^1)$, such that $j\ge k=\min_{1\le r\le H}\{k_r\}$, define $S_L^X(m_r)=\left\{S_i^X=\sum_{t=0}^{k_r-2}d_{i+t}^X : i\in\mathsf{I}_{j-(k_r-1)}^1\right\}$, then X is a failed state if there exists $(i,r)\in\mathsf{I}_{j-(k_r-1)}^1\times\mathsf{I}_H^1$, such that $S_i^X\prec m_r$.

Proof: The proof is the same as in *lemma 2.1* but the condition $i\in\mathsf{I}_{j-(k_r-1)}^1$ is to exclude the effects of the connection between the 1st and the nth components.

For example, the state $\{169\}\in[127]\in\Psi_C^{(2,3),(3,5),9}$, since $S_C^{169}(3)=\{1,3,5\}, S_3^X=1\le 3$, while $\{169\}\notin\Psi_L^{(2,3),(3,5),9}$, and $S_L^{169}(3)=3,5\ge 3$, and $S_L^{169}(5)=8\ge 5$

Lemma 3.2: Consider the linear (circular) consecutive-**k**-out-of-**m**-from-*n*: F system with multiple failure criteria is in the functioning state, and $M^{L(C)}$ is the maximum number of failed components, then $M^{L(C)} = \min_{1\le r\le H}\left\{M_r^{L(C)}\right\}$.

Proof: Assume that $M^{L(C)} > M_i = \min_{1\le r\le H}\left\{M_r^{L(C)}\right\}$, then WLOG, the consecutive-k_i-out-of-m_i-from-n: F linear (circular) system is in the failure state, which implies that the consecutive-**k**-out-of-**m**-from-*n*: F linear (circular) system is in the failure state, which contradicts the assumption.

4. The proposed algorithm

If *j* is the number of the failed components in the consecutive-**k**-out-of-**m**-from-*n*: F linear and circular system with multiple failure criteria, and $k = \min_{1\le r\le H}\{k_r\}, M^{L(C)} = \min_{1\le r\le H}\left\{M_r^{L(C)}\right\}$, then the failure $\mathsf{F}_j^{L(C)}$ and reliability $\mathsf{R}_j^{L(C)}$ functions are given using the following:

- ♦ For j=0,1, …, k-1, all states are in the functioning state, then $\mathsf{R}_j^{L(C)} = \binom{n}{j} p_n^{n-j}$ and $\mathsf{F}_j^{L(C)} = 0$
- ♦ Using (lemma 3.2), For j=k, k+1, …, $M^{L(C)}$, find $d_X = \left(d_1^X, d_2^X, ..., d_j^X\right)$.
- ♦ Using Nashwan (2018), find the corresponding $X \in P\left(\mathsf{I}_n^1\right)$ and compute $[X]$
- ♦ Foreach $r \in \mathsf{I}_H^1$, compute $S_C^X(m_r) = \left\{S_i^X : i \in \mathsf{I}_j^1\right\}$. If there exists $S_i^X \in S_C^X(m_r)$ such that $S_i^X \prec m_r$, then $X \in \Psi_C^{\mathbf{k},\mathbf{m},n}$, otherwise $X \in \Theta_C^{\mathbf{k},\mathbf{m},n}$ (*lemma 2.1*).
- ♦ For the linear system,
- - If $X \in \Theta_C^{\mathbf{k},\mathbf{m},n}$ then $[X] \in \Theta_L^{\mathbf{k},\mathbf{m},n}$
- - If $X \in \Psi_C^{\mathbf{k},\mathbf{m},n}$, check $S_L^Y(m_r) = \left\{S_i^Y : i \in \mathsf{I}_{j-(k_r-1)}^1\right\}$ for all $Y \in [X]$.(*lemma 3.1*)
- - Add all Y that does not hold the condition of lemma 3.1 to $\Theta_L^{\mathbf{k},\mathbf{m},n}$.
- - The $\Theta_L^{\mathbf{k},\mathbf{m},n}$ consists of $\Theta_C^{\mathbf{k},\mathbf{m},n}$ and all Y does not hold the condition of *lemma 3.1.* in 5.3.
- ♦ Finally, it is obvious that $\mathsf{R}_j^{L(C)}\left(\mathsf{F}_j^{L(C)}\right)$, the summation of the reliability (failure) function of the classes $[X] \in \Theta_{L(C)}^{\mathbf{k},\mathbf{m},n}\left(\Psi_{L(C)}^{\mathbf{k},\mathbf{m},n}\right)$, where $|X| = j$.
- ♦ Using (*lemma 3.2*) again, for $j > M^{L(C)}$, all states are failed, hence $\mathsf{F}_j^{L(C)} = \binom{n}{j} p_n^{n-j}$ and $\mathsf{R}_j^{L(C)} = 0$.
- ♦ The reliability function of the system is $\mathsf{R}_{L(C)} = \sum_{j=0}^{n} \mathsf{R}_j^{L(C)}$, while the failure function is $\mathsf{F}_{L(C)} = \sum_{j=k}^{n} \mathsf{F}_j^{L(C)}$.

Example 4.1:

The reliability and the failure functions of the (2,3)-out-of-(3,5)-from-9: F linear and circular system

$$M^{L(C)} = 3$$

For j=0, 1 all states are in the functioning states, i.e. $\mathsf{F}_j^{L(C)} = 0, \quad \mathsf{R}_j^{L(C)} = \binom{n}{j} p_n^j$

For j=2

$d_{\{1,2\}} = (1,8) \Rightarrow S_C(3) = \{1,8\}, S_C(5) = \{9\}$

$[12] = \{12,23,34,45,56,67,78,89,\underline{19}\} \in \Psi_C^{(2,3),(3,5),9}$,

$S_L^{\{19\}}(2) = \{8\} \Rightarrow \{19\} \in \Theta_L^{(2,3),(3,5),9}$

$d_{\{1,3\}} = (2,7) \Rightarrow S_C(3) = \{2,7\}$,

$S_C(5) = \{9\}, W_1^{\{18\}}(2) = W_1^{\{29\}}(2) = 7 \Rightarrow$

$[13] = \{13,24,35,46,57,68,79,\underline{18},\underline{29}\} \in \Psi_C^{(2,3),(3,5),9}$,

$S_L^{\{18\}}(2) = S_L^{\{29\}}(2) = \{8\} \Rightarrow \{18,29\} \in \Theta_L^{(2,3),(3,5),9}$

$d_{\{1,4\}} = (3,6) \Rightarrow S_C(3) = \{3,6\}, S_C(5) = \{9\} \Rightarrow$

$[14] = \{14,25,36,47,58,69,17,28,39\} \in \Theta_C^{(2,3),(3,5),9}$

$d_{\{1,5\}} = (4,5) \Rightarrow S_C(3) = \{4,5\}, S_C(5) = \{9\} \Rightarrow$

$[15] = \left\{\begin{matrix}15,26,37,48,59,16,27,\\ 38,49\end{matrix}\right\} \in \Theta_C^{(2,3),(3,5),9}$

$\mathsf{F}_2^C = 18p_9^2 \qquad \mathsf{R}_2^C = 18p_9^2$

$\mathsf{F}_2^L = 15p_9^2 \qquad \mathsf{R}_2^L = 21p_9^2$

For j=3

$[123]=\{123,234,345,456,567,678,789,189,129\}\in\Psi_C^{(2,3),(3,5),9}$

$[124]=\{124,235,346,457,568,679,178,289,139\}\in\Psi_C^{(2,3),(3,5),9}$

$$[125]=\left\{\begin{matrix}125,236,347,458,569,167,\\ 278,389,\underline{149}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{149\}}(5)=\{8\}\Rightarrow\{149\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[126]=\left\{\begin{matrix}126,237,348,459,156,267,\\ 378,489,\underline{159}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{159\}}(5)=\{8\}\Rightarrow\{159\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[127]=\left\{\begin{matrix}127,238,349,145,256,367,\\ 478,589,\underline{169}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{159\}}(5)=\{8\}\Rightarrow\{169\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[128]=\left\{\begin{matrix}128,239,134,245,356,467,\\ 578,689,179\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9}$$

$$[135]=\left\{\begin{matrix}135,246,357,468,579,168,\\ 279,138,249\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9}$$

$$[136]=\left\{\begin{matrix}136,247,358,469,157,268,\\ 379,\underline{148},\underline{259}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{148\}}(5)=S_L^{\{259\}}(5)=\{7\}\Rightarrow$$
$$\{148,259\}\in\Theta_L^{(2,3),(3,5),9}$$

$$[137]=\left\{\begin{matrix}137,248,359,146,257,368,\\ 479,\underline{158},\underline{269}\end{matrix}\right\}\in\Psi_C^{(2,3),(3,5),9},$$

$$S_L^{\{158\}}(5)=S_L^{\{269\}}(5)=\{7\}\Rightarrow\{159,269\}\in\Theta_L^{(2,3),(3,5),9}$$

$$\mathsf{F}_3^C=81p_9^3 \qquad \mathsf{R}_3^C=3p_9^3$$
$$\mathsf{F}_3^L=74p_9^3 \qquad \mathsf{R}_3^L=10p_9^3$$

For $j\geq 4$ all states are in the failure states, hence $\mathsf{F}_j^{L(C)}=\binom{9}{j}p_9^{9-j}$, $\mathsf{R}_j^{L(C)}=0$, then, the reliability functions of the linear and the circular systems

$$\mathsf{R}_L=\sum_{j=0}^{9}\mathsf{R}_j^C=p_9^0+9p_9^1+21p_9^2+10p_9^3$$
$$\mathsf{R}_C=\sum_{j=0}^{9}\mathsf{R}_j^C=p_9^0+9p_9^1+18p_9^2+3p_9^3,$$

and the failure probability functions of the linear and the circular systems

$$\mathsf{F}_L=\sum_{j=2}^{9}\mathsf{F}_j^C=15p_9^2+74p_9^3+126p_9^4$$
$$+126p_9^5+81p_9^6+36p_9^7+9p_9^8+p_9^9$$

$$\mathsf{F}_C=\sum_{j=4}^{9}\mathsf{F}_j^C=18p_9^2+81p_9^3+126p_9^4$$
$$+126p_9^5+81p_9^6+36p_9^7+9p_9^8+p_9^9$$

CONCLUSION

In this paper, we proposed an algorithm to find the reliability and the failure probability functions of the consecutive-**k**-out-**m**-from-*n*: F linear and circular system with multiple failure criteria. In this context, we determined the collections of all failure and the functioning states, where the collection of failure states of the linear type is a sub collection of the circular one. Moreover, we computed the maximum possible number of the failed components in the working consecutive-**k**-out-**m**-from-*n*: F linear and circular systems with multiple failure criteria.

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Data Mining Techniques for Prediction of Concrete Compressive Strength (CCS)

تقنيات التنقيب في البيانات للتنبؤ بالقوة الانضغاطية الخرسانية

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Abstract

The main aim of this research is to use data mining techniques to explore the main factors affecting the strength of concrete mix. In this research, we are interested in finding some of the factors that influence the high performance of concrete to increase the Concrete Compressive Strength (CCS) mix. We used Waikato's Knowledge Analysis Environment (WEKA) tool and algorithms such as K-Means, Kohonen's Self Organizing Map (KSOM) and EM to identify the most influential factors that increase the strength of the concrete mix. The results of this research showed that EM is highly capable of determining the main components that affect the compressive strength of high performance concrete mix. The other two algorithms, K-Means and KSOM, were noted to be an advanced predictive model for predicting the strength of the concrete mix.

Keywords: Data Mining, Concrete Compressive Strength (CCS), K-means, EM Algorithm, Kohonen's Self-Organizing Map (KSOM) , Clustering.

ملخص:

هدف البحث الرئيس، هو استخدام تقنيات استخراج البيانات لاكتشاف العوامل الرئيسية التي تؤثر في قوة مزيج الخرسانة. إن جل اهتمامنا في هذا البحث، هو إيجاد بعض العوامل التي تؤثر في الأداء العالي للخرسانة لزيادة مزيج قوة ضاغطة الخرسانة. لتحقيق هذا الهدف، استخدمنا أداة Waikato's Environment Analysis Environment (WEKA) وخوارزميات مثل K-Means وخريطة كوهن ذاتية التنظيم (KSOM) و EM لتحديد العوامل الأكثر تأثير والّتي تزيد من قوة مزيج الخرسانة. أظهرت نتائج هذا البحث أن EM يظهر أهمية كبيرة لتحديد المكونات الرئيسية التي تؤثر في قوة الضغط للمزيج الخرساني عالي الأداء. بينما تعد الخوارزميات K-Means و KSOM نموذجًا تنبؤيًا متقدمًا لقوة الخلطة الخرسانية.

كلمات مفتاحية: تعدين البيانات، قوة الضغط الخرسانية EM ،K-means،(CCS) خوارزمية ، خريطة كوهن ذاتية التنظيم (KSOM).

INTRODUCTION

Technical engineers and laboratories are required to obtain and test the strength and the accuracy of concrete. Testing modeling at the laboratory is both, time and cost consuming (Agrawal V. and Sharma A., 2010) as it includes most of the ingredients or components that are required for designing concrete. The traditional approaches focus on understanding and modeling the effects of the components on the strength of concrete (Chen L. and Wang T. S., 2010). Nowadays, the situation has changed with the rapid spread of information technology. In the recent years, different techniques of Artificial Intelligence (AI) and Data Mining were used to predict the main factors that affect the concrete strength. Recently, there has been many applications and approaches that are based on Artificial Intelligence and Data Mining in Civil Engineering (Chen L. and Wang T. S., 2010; Jain et al., 1994; Flood I., and Kartam N., 1994).

Concrete is the major building material that is used around the world. Concrete mainly consists of three basic components that are mixed in measured proportions. These components are, water, portland cement and aggregate (gravel, sand and rock). They all form a solid material called concrete. Concrete is well known for its high compressive strength, impermeability, fire resistance, durability and abrasion resistance.

There are several factors that affect the strength of High Performance Concrete (HPC). Ration of water to cement may be considered the main factor, but it is also induced by the components of the concrete like cement, blast furnaces slag, fly ash, water, super plasticizer, coarse aggregate, fine aggregate and age.

Using Data Mining will provide advice, assistance and indication of signs to enhance Concrete Compressive Strength (CCS) by finding the main factors that influence the compressive strength of concrete and its high performance.

This study focuses on identifying the list of components that affect Concrete Compressive Strength (CCS) by using data mining Algorithms to assist in predicting and identifying the main necessary components to identify high performance compressive strength of concrete.

This study is based on publicly available resources of UCI Machine Learning Repository with eight parameters and one output. We used three different data mining algorithms. These algorithms are K-Means, Kohonen's Self Organizing Map (KSOM) and EM and applied them on the dataset. According to the analysis of the data and the results, the most accurate result is achieved by EM for predicting the key components that affect the compressive strength of concrete. On the other hand, K-Means and KSOM can be used as an effective tool for predicting concrete compressive strength.

In this paper, we start with the literature review of the research papers (section 2). An overview of data mining techniques in civil engineering is then presented in section3. In Section 4, we explain in details the methodological approaches used throughout this study, followed by a discussion regarding the findings of this research (Section 5). Finally, a summary and conclusion are presented in Section 6.

Literature Review

In the recent years, Artificial Intelligence played essential roles in solving problems that are difficult to address through the traditional programming or human experts. Researcher used data mining and ANN for solving many problems in many fields such as, tourism, finance, banking, aerospace, airplane navigation, life insurance, automotive, terrorism, defense, fault detection in electric and electronics, telecommunications, entertainment, control systems in industry, automotive of manufacturing, transportation (Arciszewski, et al, 1994), agriculture (Abuzir Y., 2018), smart cities, civil engineering, medicine, image processing, robotics, speech recognition and information securities.

Data Mining Technique (DMT) applications have become more numerous and more important in many areas. By using DMT, we are able to see a transformation and obtain new knowledge or skills in many fields, as well as allow or plan for a certain possible new future applications (Shu et al, 2011).

In the literature Review, there are different approaches and studies that focus on finding the appropriate properties for designing concrete and predicting the Concrete Compressive Strength (CCS) using Artificial Intelligence techniques.

Ozcan et al., in their research proposed Artificial Neural Networks to predict long-term compressive strength of silica fume concrete (Ozcan et al, 2009). Another researcher used neural network for predicting Concrete Compressive Strength (CCS) with different water/cement ratios. In the input layer of the neural network model, they used the following five input parameters: water/binder ratio, binder/sand ratio, metakaolin percentage, superplasticizer percentage, and age. The proposed neural network model predicts the compressive strength of mortars only (Saridemir M., 2009).

Neural Network model are based on four input parameters prediction models used for predicting compressive strength of concrete. The input layer employed the following four parameters: Water-to-binder ratio, cement content, curing conditions, and age (Yaprak et al, 2011).

(Tinoco et al., 2010) used Data Mining technique as a prediction model for uniaxial compressive strength (UCS) of JG materials. They showed their model are able to identify with high accuracy the complex relationship between the UCS of JG material and its contributing factors.

Another approach is based on combining conventional method with the artificial intelligence method to design a predictive model for a concrete compressive strength. The results showed that their model is accurate and suitable for predicting the compressive strength development (Liu G. and Zheng J., 2019).

DATA MINING IN CIVIL ENGINEERING

An Overview of Data Mining and Weka

Data mining is a process or a technique of applying different algorithms on a large dataset for extracting beneficial information or knowledge.

Intelligent tools are required to apply data mining techniques to manipulate datasets.

Data mining is often used as a combination of intelligent and unconventional sciences like business analytics, mathematics, logic, statistics, artificial intelligence, machine learning and artificial neural networks (Mohammed, 2016), (Abuzir Y. and Baraka A.M, 2019).

The analytic techniques used in data mining often share or use the following Data Mining algorithms (Brown, 2012), (Patel et al., 2014):

- Classification
- Clustering
- Association
- Prediction
- Sequential patterns
- Decision trees

Data mining involves five steps: Data selection, data cleaning, data transformation, pattern evaluation and knowledge presentation and finally decisions / use of discovered knowledge as shown in the Figure 1

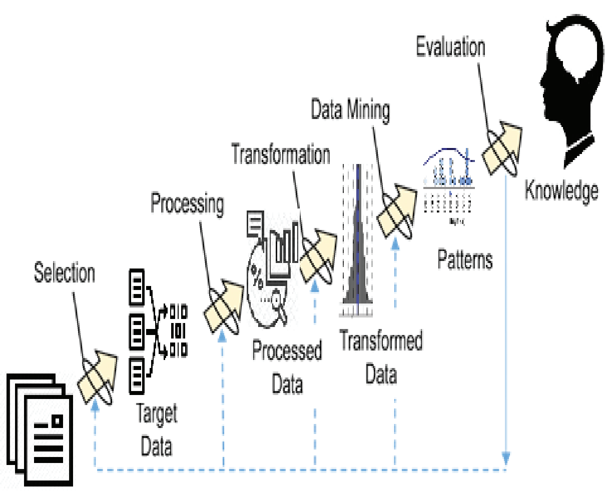


Figure 1

The main steps in Data mining

WEKA is abbreviation for Waikato's Knowledge Analysis Environment. It is an open source tool developed by the University of Waikato in New Zealand. WEKA is a Java based tool that involves many open source data mining and machine learning algorithms. WEKA has the following features (Alka, et al. 2017):

- Data processing tools.
- Classification, clustering algorithms and association.
- User interface and graphical interface.
- WEKA data mining and machine learning tools

The Use of Data Mining in Civil Engineering

Nowadays, a lot of data and information related to civil engineering field are available on online repositories of the research centers. Researchers can use this information and apply different data analysis to obtain important information to support their research papers. They can use data mining techniques in many areas of Civil Engineering.

In the field of civil engineering, many research papers apply different approaches of Data Mining and Artificial Neural Network (ANN) technologies (Deepa et al. 2010; Guneyisi, et al., 2009; Topcu I.B, Sarıdemir M., 2007). Different studies applied data mining techniques and ANN the following areas of civil engineering (Kaplinski, et al., 2016; Topcu, et al., 2009):

- Predicting properties of conventional concrete (Guneyisi, et al., 2009).
- Predicting high performance compressive strength of concretes (Ozcan et al, 2009; (Nikoo, et al., 2015), (Han, et al., 2019; Young et al., 2018).
- Concrete mix proportions (Topcu I.B, Sarıdemir M. , 2007) [15] (Young et al., 2018).
- Predict the concrete durability (Yaprak, et al., 2009) [5] (Pann et al, 2003).
- Modeling of material behavior (Bock et al, 2019),
- Detection of structural damage (Fanga, et al., 2005),
- Structural system identification (Chou, et al., 2014),
- Structural optimization (Tanyildizi, H. 2009),
- Structural control, ground water monitoring (El-Kholy, A. M. 2019),
- Prediction of settlement of shallow foundation (Pann, et al. 2003)

MATERIALS AND METHODS

Most of the previous studies attempted to investigate, study and model the effects of the components on the strength of the concrete. In the recent years, new approaches utilized Artificial Intelligence (AI) and Data Mining techniques to predict the main factors that affect the concrete strength.

The main contributions of our approach is twofold. First, it focuses on using all the different components that compose the concrete, to study the main factors that influence the high performance of the concrete, to increase the Concrete Compressive Strength (CCS) mix. Second, we try to find a better and more accurate prediction model for CCS. We can summarize our contributions in the following points:

- ♦ The study uses three different algorithms K-Means, Kohonen's Self Organizing Map (KSOM) and EM.
- ♦ The study determines which is the best algorithm that can be used to identify the main factors that influence the strength of concrete.

The study identifies the best algorithm that can be used as an advanced prediction model for the strength of concrete mix.

This research utilized data mining techniques to predict the key components that affect the strength of concrete. WEKA tool provides us with different tools to analyze the dataset and apply different algorithms such as EM, Kohonen's Self Organizing Map (KSOM) and K-Means. The following paragraphs and subsections discuss the characteristics of the datasets and algorithms used in this study. It discusses in details the methodological approach used to develop the prediction model of the main key factors that affect the compressive strength of concrete.

Data Sets

Compressive strength concrete dataset from UCI Machine learning Repository (Yeh I. C., 1998) is used as the experimental data sets of 1030 cases. In the data set, there are eight input parameters and one output value Concrete Compressive Strength (CCS). These parameters are cement, blast furnaces slag, fly ash, water, super plasticizer, coarse aggregate, fine aggregate and age. For the first seven parameters, we use kg/m3 and for the eighth parameter age, we use number of days for the laboratory test of the concrete sample.

We obtained the statistical analysis using Weka to create Table 1 and represent it using graphs in Figure 2. Table 1 lists a general statistical information on the eight factors. These statistics are computed by WEKA. The table shows the maximum, minimum , the average, the mean and the Standard deviation for each factors. Weak supports users though two methods to split data.

The first method is training and supplied test set. The second method is a percentage split and these groups are not included with each other during the training phase. To conduct the statistical analysis of the datasets, we divided the dataset into two groups: A training set (721 samples) amounting to70%, and a testing set (309 samples) amounting to 30% of the group. After splitting the data into training and testing sets, the statistical analysis and data mining algorithms were applied to present the results.

Table 1

Concrete Strength Data Sets Components Ranges (WEKA)

Name of Component	Maximum (kg/m3 mixture)	Minimum (kg/m3 mixture)	Average Value (kg/m3 mixture)	Mean	SDV
Cement	540	102	321	281.16	104.50
Blast Furnace	359.40	0	179.7	73.896	86.279
Fly Ash	200.10	0	100.05	54.188	63.997
Water	247	121.75	184.375	181.56	21.354
Superplasticizer	32.20	0	16.1	6.205	5.974
Coarse Aggregate	1145	801	973	972.91	77.754
Fine Aggregate	992.60	594	793.3	773.58	80.176
Age of testing	365 days	1 day	183 days	45.662	63.17

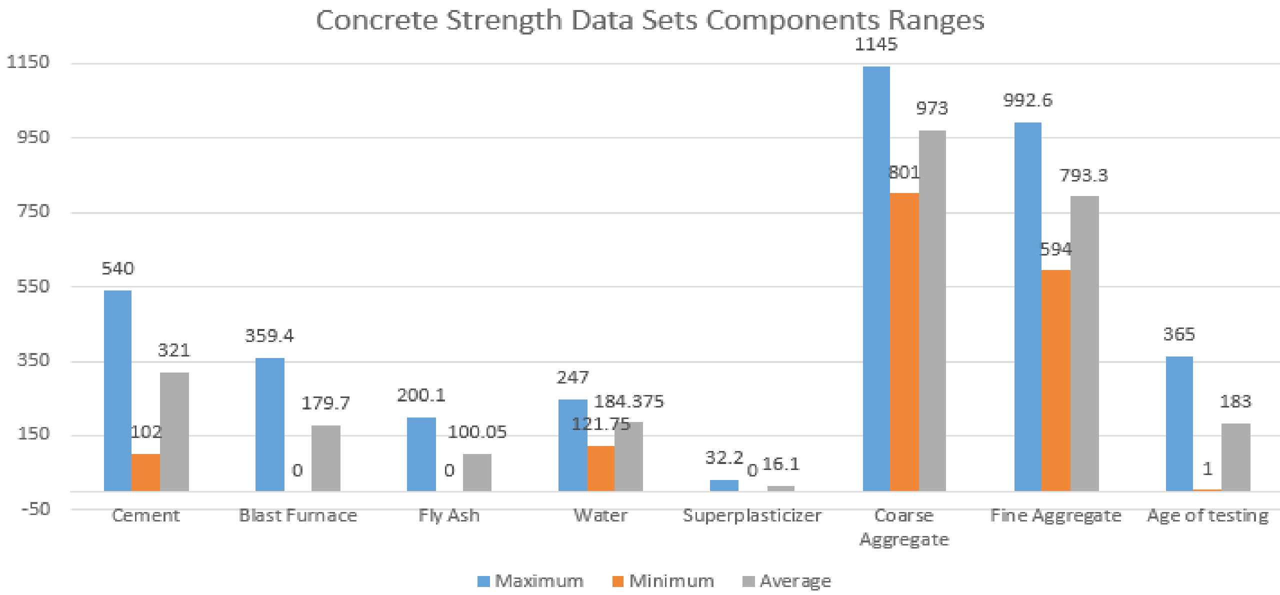


Figure 2.

Concrete Strength Data Sets Components Ranges

DATA MINING ALGORITHMS

This section presents the different machine learning algorithms used in finding the main factors that affect the compressive strength of the concrete. EM is one of the clustering algorithms used in data mining. It uses two iterative steps called E-step and M-step:

- ♦ E-step, where each object assigned to the most likely cluster(centroids).
- ♦ M-step, where the model (centroids) are recomputed (Least Squares Optimization).

Another algorithm is Kohonen Self-Organizing Map (KSOM). It is one of the most adopted neural network in unsupervised learning. (Fernando, 2015).

K-means algorithm is a clustering algorithm, given the data <x1, x2,…,xn> and K, assign each xi to one K clusters, C1…Ck, minimizing equation 1 (Khedr et. al, 2014), equation (1) used to find Sum of Squared Error (SSE)

$$SSE = \sum_{j=1}^{K} \sum_{x_i \in c_j} \left\| x_i - \mu_j \right\|^2. \qquad (1)$$

Where

K is the number of desired clusters

is mean over all points in cluster Cj.

The following Algorithm is used to apply K-Means:

1. Set randomly

2. Repeat until convergence:

- Assign each point xi to the cluster with closest mean
- Calculate the new mean for each cluster (equation 2)

$$\mu j = \frac{1}{|c_j|} \sum_{x_i \in c_j} x_i \quad \text{........................(2)}$$

Figure 3 presents a schematic illustration of prediction mechanisms using the three machine-learning algorithms of simple K-Means, KSOM and EM.

We utilized the EM, KSOM and K-means algorithms for finding the main components in concrete mix that affect the compressive strength of concrete. The study applied these algorithms with different configurations of both, the algorithms and the dataset. Then the study analyzed the results along with an evaluation of the different configurations of the results. The simplest approach is to find the parameter that minimizes scores of the different parameters like Standard Deviation (STD) and Root Mean Squared Error (RMSE).

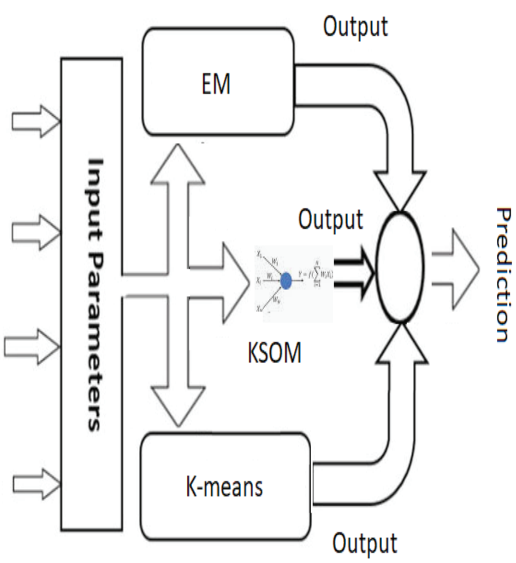


Figure 3

Schematic illustration of prediction using EM, KSOM and K-Means Algorithms.

RESULTS AND DISCUSSION

In this research, the dataset is first selected, then data mining techniques are utilized in finding the parameters. In general, eight parameters (cement, blast furnaces slag, fly ash, water, super plasticizer, coarse aggregate, fine aggregate and age) were examined against concrete compressive strength using three data mining algorithms. This section discusses, compares and evaluates these algorithms using concrete dataset to investigate the main factors that affect concrete mix strength.

Table 2 represents the primary results of EM algorithm. To get the result, different datasets were used with different numbers of clusters (K=3,5,7,and 9) as shown in Table 2.

For each number of clusters, we computed different statistical values. In our case, we used standard deviation as a statistical measure to select the main factors that affect the CCS. Table 2 summarizes our calculations and shows only the most influential factors on the CCS. For example, when K=5, we find that the following three factors blast furnaces slag, fly ash, and super plasticizer imapct the CCS.

The values show the different results of predicting the main factors that affect Concrete Compressive Strength (CCS) using EM algorithm based on eight components of concrete mix. These results are computed and visualized using WEKA Tool.

Figure 4 shows the relationship between the main components that affect the concrete mix and the parameter Concrete Compressive Strength (CCS) using EM Algorithm. As shown in these figures, the values of Concrete Compressive Strength (CCS) as a function computed based on Superplasticizer, Fly Ash and Blast Furnace Slag serve obtained high similarity values.

Table 2.

Screen dumps of the results of EM Algorithms Using WEKA

Number of Clusters	Results of EM
EM (with K= 3)	Superplasticizer mean std. dev.
EM (with K= 5)	Blast Furnace Slag mean 71.726 std. dev. 69.762 Fly Ash mean 8.6447 std. dev. 30.1856 Superplasticizer mean 0.34 std. dev. 1.18

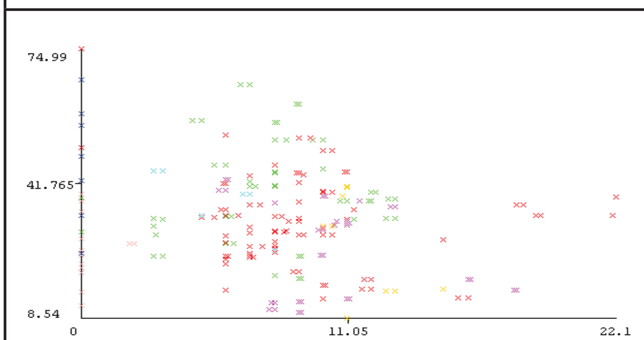
Number of Clusters	Results of EM									
EM (with K= 7)	Blast Furnace Slag									
	mean	23.1165	140.6642	82.718	0	26.5337	192.7328	22.9621		
	std. dev.	23.3759	65.9588	73.0192	0.0002	51.3771	61.611	40.8663		
	Fly Ash									
	mean	110.9131	0.0035	0.0107	0	1.5761	0.4274	120.6712		
	std. dev.	26.8864	0.2928	1.0604	61.4471	8.8978	3.2074	32.6375		
	Superplasticizer									
	mean	10.2752	14.6176	0.0006	0	3.0277	0.5002	7.9891		
	std. dev.	3.8984	6.4238	0.0616	0.0004	5.3601	1.9652	2.9272		
EM (with K= 9)	Blast Furnace Slag									
	mean	4.0644	90.9507	82.6599	8.8915	175.5803	0.4714	21.0026	33.7256	182.1985
	std. dev.	13.4621	48.8117	72.6721	29.1616	78.743	2.3478	5.7829	44.2412	48.6432
	Fly Ash									
	mean	110.9131	0.0035	0.0107	0	1.5761	0.4274	120.6712		
	std. dev.	26.8864	0.2928	1.0604	61.4471	8.8978	3.2074	32.6375		
	Superplasticizer									
	mean	0.9103	17.5907	0.0002	0.5885	0.0253	7.479	10.4851	8.4821	11.8749
	std. dev.	2.3356	7.5873	0.036	1.8861	0.3856	3.3652	3.8487	2.4399	3.313

After designing EM model for predicting the main factors that affect concrete compressive strength and analyzing the results obtained by the EM algorithm, it is clear that the EM algorithm achieves the optimal mix of the concrete components.

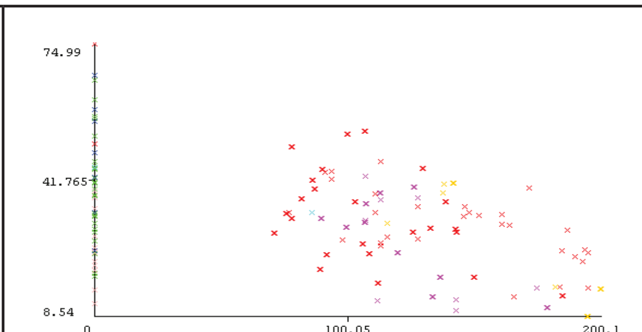
After running the EM algorithm on the dataset for a number of times with varied values for number of clusters, the best parameters were selected based on their Standard deviation values. Table 3 shows the list of the main factors that affect Concrete Compressive Strength (CCS) with their standard deviations.

Figure. 4 illustrates the values of concrete compressive strength predicted by the EM algorithm versus the other components such as Superplasticizer, Fly Ash and Blast Furnace Slag, for both training and testing datasets. As shown in figure 4, there is a consistent indication among the different combinations of the three components and the concrete compressive strength. It is clear that the distribution of points in the three planes shows the same picture.

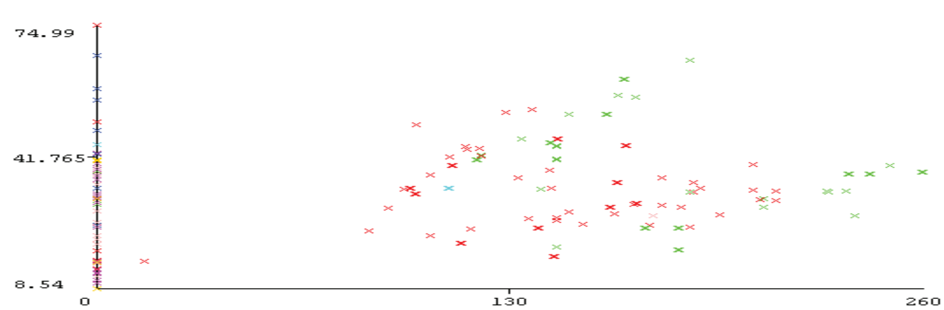
EM with 9 Clusters



X: Superplasticizer , Y : Concrete compressive strength



X: Fly Ash , Y : Concrete compressive strength



X: Blast Furnace Slag , Y : Concrete compressive strength

Figure 4.

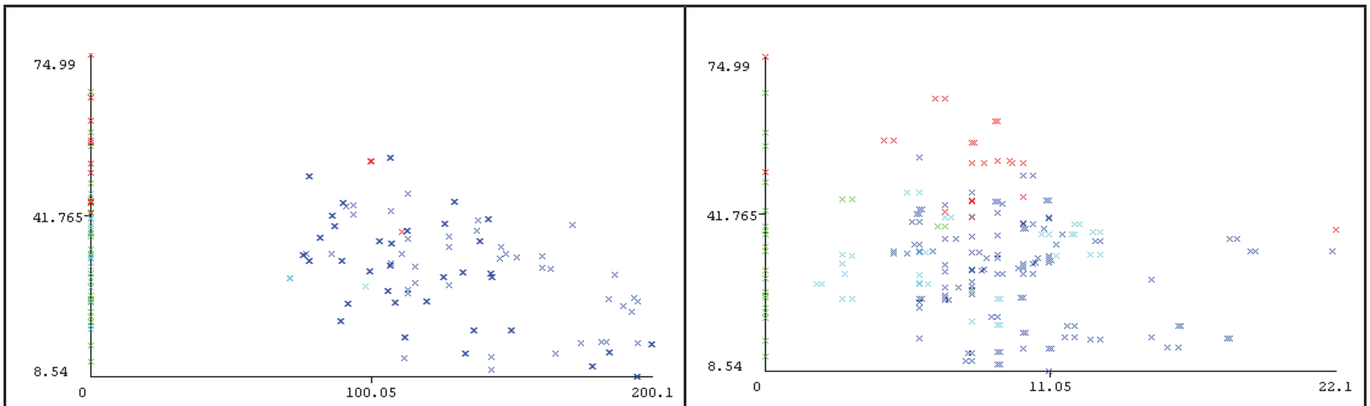
Plotting of the main components the affect the concrete using EM Algorithm

Table 3.

List of the main components that affect compressive strength of concrete (EM)

Number of Clusters	Standard. Deviation	Predict Components
3	0.0001	Superplasticizer
	0.015	Blast Furnace Slag
5	3.265	Fly Ash
	0.2488	Superplasticizer
	0.0004	Superplasticizer
7	0.2928	Fly Ash
	0.0002	Blast Furnace Slag
	0.0001	Superplasticizer
9	0.0148	Fly Ash
	2.3478	Blast Furnace Slag

The second model use the KSOM algorithm. This algorithm is employed to illustrate the components that affect concrete compressive strength. In the KSOM algorithm, the main components that affect the Concrete Compressive Strength (CCS) are Fly Ash and Superplasticizer. Figure 5 shows the results.



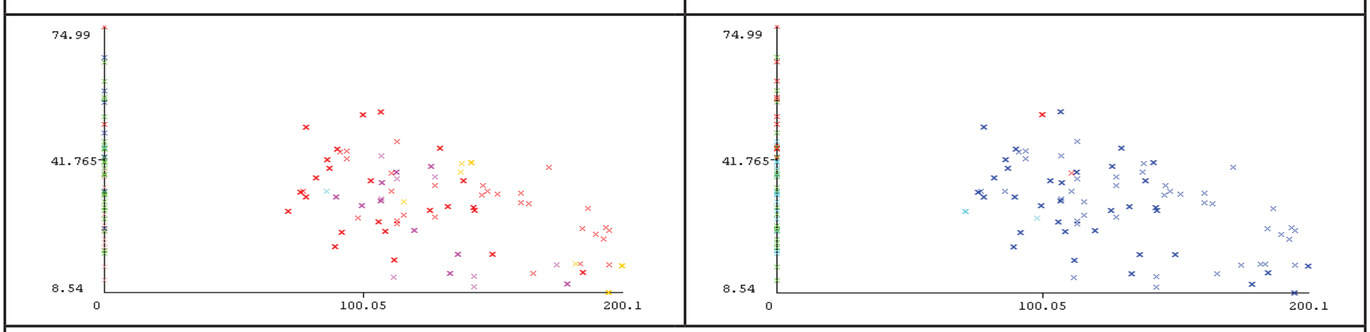
X: Fly Ash , Y : Concrete Compressive Strength | X: Superplasticizer, Y : Concrete Compressive Strength

Figure 5.

Fly Ash and Superplasticizer versus Concrete Compressive Strength (KSOM)

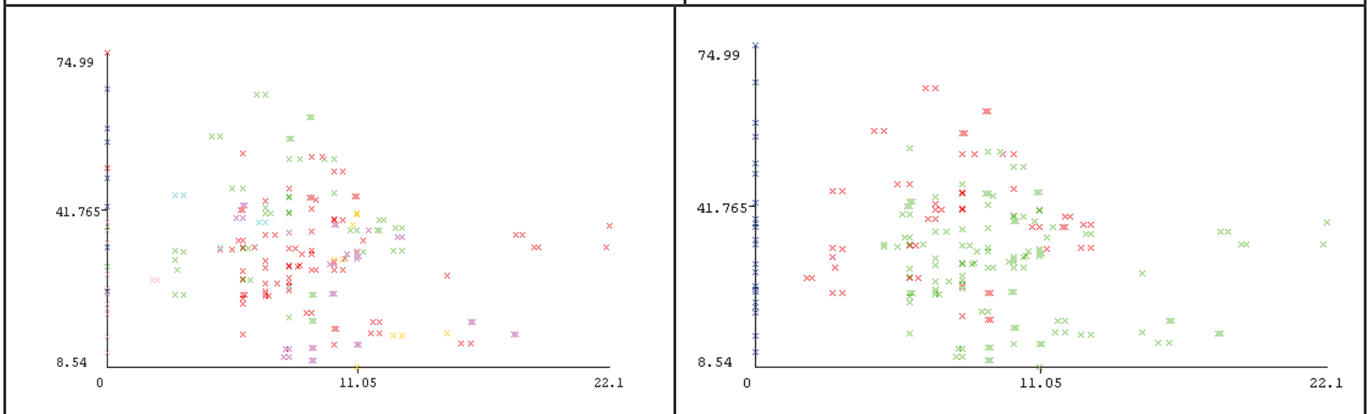
Figure 6 illustrates a comparison between the EM and KSOM algorithms. As the figure shows, the predicted models for the two components are highly similar. The performance of fly ash on concrete compressive strength has the same significant effect. The analysis of the two graphs shows that the two algorithms have the same effect among the potentially used two input parameters, fly ash and Superplasticizer.

EM | **KSOM**



X: Fly Ash , Y : Concrete Compressive Strength

EM	KSOM



X: Superplasticizer, Y : Concrete Compressive Strength

Figure 6.

Comparing EM and KSOM Algorithms

The K-means algorithm is applied to the datasets, using different value for k = 3,5,7 and 9. Table 4 shows the results of clustering with the different value for K= 3,5, 7 and 9.

Based on the analysis of the result of K-Means we find that the factors that mostly affect the compressive strength on concrete mix are Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate (Table 5). According to the results, Table 6 presents a summary of the key attributes that affect the concrete compressive strength using the three different algorithms.

Referring to the results in table 6, K-Means algorithm shows that Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate are the most common components that affect the Concrete Compressive Strength (CCS) mix. In EM and KSOM algorithms two common component are considered, Fly Ash and Superplasticizer. At the same time, EM algorithms includes a distinguished component which is the Blast Furnace Slag. It is clear that, all the three algorithms show intersection and provide different information. In general, the analysis concludes that Fly Ash and Superplasticizer are common components and they are the two main factors that affect concrete compressive strength.

Table 4.

Screen dumps of the Results For K-Means (with K= 3,5, 7 and 9)

Number of Clusters	Results For K-Means (with K= 3,5, 7 and 9)
K-Means (with K= 3)	Final cluster centroids:

Attribute	Full Data (806.0)	Cluster# 0 (360.0)	1 (295.0)	2 (151.0)
Cement	292.8646	284.8378	246.1525	403.2603
Blast Furnace Slag	67.3143	83.2689	18.9129	123.8358
Fly Ash	47.4553	0.9153	124.3339	8.2185
Water	179.8442	197.2456	169.0492	159.447
Superplasticizer	5.6511	0.2769	8.3688	13.1543
Coarse Aggregate	985.786	992.7369	1001.0068	939.4781
Fine Aggregate	778.3337	755.3672	805.9288	779.1775
Age	49.5546	64.5111	37	38.4238
Concrete compressive strength	36.5954	28.7541	35.4996	57.4306

Number of Clusters	Results For K-Means (with K= 3,5, 7 and 9)

K-Means (with K= 5)

Attribute	Full Data (806.0)	Cluster# 0 (149.0)	1 (297.0)	2 (88.0)	3 (57.0)	4 (215.0)
Cement	292.8646	200.2141	247.4983	373.85	428.8509	350.5428
Blast Furnace Slag	67.3143	187.5711	18.9471	148.1057	95.4404	10.2628
Fly Ash	47.4553	1.3154	124.0286	13.142	0	0.2791
Water	179.8442	196.4242	169.0017	164.6159	150.293	197.3991
Superplasticizer	5.6511	0.594	8.3906	11.0352	17.4947	0.0279
Coarse Aggregate	985.786	974.1993	1000.7778	978.5557	868.3368	1007.2033
Fine Aggregate	778.3337	751.1007	805.2963	729.2545	875.9649	754.1656
Age	49.5546	45.3356	36.798	38.1705	35.0877	78.5953
Concrete compressive strength	36.5954	26.3142	35.5209	59.998	53.5979	31.1184

K-Means (with K= 7)

Final cluster centroids:

Attribute	Full Data (806.0)	Cluster# 0 (128.0)	1 (244.0)	2 (79.0)	3 (60.0)	4 (66.0)	5 (164.0)	6 (65.0)
Cement	292.8646	194.9336	215.3877	368.1253	431.1583	357.6136	329.2226	399.9446
Blast Furnace Slag	67.3143	192.768	18.7746	157.7367	96.6083	66.4136	4.4921	24.9585
Fly Ash	47.4553	0	125.3332	3.2278	0	0	1.0457	111.4031
Water	179.8442	195.3016	168.8914	165.0646	151.8333	217.4318	190.7787	168.5846
Superplasticizer	5.6511	0.2008	7.982	10.6076	17.065	0	0.3262	10.2477
Coarse Aggregate	985.786	970.3328	1020.9295	995.5886	867.525	958.9697	1022.5116	916.1108
Fine Aggregate	778.3337	758.6336	811.9779	722.6987	871.2417	660.6455	789.5463	763.8985
Age	49.5546	30.1406	39.5164	38.2278	36.25	213.5	33.1768	26.3692
Concrete compressive strength	36.5954	24.2441	33.5362	59.637	54.4978	45.3738	25.4502	47.0786

K-Means (with K= 9)

Final cluster centroids:

Attribute	Full Data (806.0)	Cluster# 0 (128.0)	1 (60.0)	2 (67.0)	3 (60.0)	4 (42.0)	5 (153.0)	6 (116.0)	7 (48.0)	8 (132.0)
Cement	292.8646	194.7477	405.5333	349.6239	431.1583	317.5524	312.0131	237.1379	473.0354	198.5303
Blast Furnace Slag	67.3143	191.7852	26.5383	188.6418	96.6083	83.2333	6.4098	2.7414	12.3229	32.5227
Fly Ash	47.4553	0	111.8	1.8284	0	0	1.6013	107.2853	2.4792	140.9803
Water	179.8442	195.8703	167.7	165.3836	151.8333	220.5714	190.4824	176.65	194	162.2659
Superplasticizer	5.6511	0.0461	10.6217	11.7821	17.065	0	0.4725	7.3328	1.0333	8.5288
Coarse Aggregate	985.786	970.4109	915.3833	979.5582	867.525	943.9619	1018.7843	985.4974	1031.3458	1048.3583
Fine Aggregate	778.3337	757.1438	761.7167	727.4851	871.2417	675.1048	802.7582	846.4509	647.5875	782.2326
Age	49.5546	31.0156	25.3333	37.4776	36.25	278.0952	36.7908	37.9397	55.1667	40.9621
Concrete compressive strength	36.5954	24.5193	47.63	58.2196	54.4978	44.5945	24.5222	30.9368	49.6467	35.8519

Table 5.

K-Means - factors that mostly affect the concrete compressive strength.

Number of Cluster	Components
3	Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate
5	Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate
7	Fly Ash, Coarse Aggregate and Fine Aggregate,
9	Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate

Table 6.

Summary of the main components that affect concrete mix using the three algorithms.

K-Means	EM	KSOM
Fly Ash, Superplasticizer, Coarse Aggregate and Fine Aggregate	Fly Ash, Superplasticizer and Blast Furnace Slag	Fly Ash and Superplasticizer

Table 7.

The relation between no. of Cluster, Sum of Squared Errors and Concrete Compressive Strength (CCS) using K-Means.

No. of Clusters	Sum Of Squared Errors (SSE)	Number Of Iterations	Concrete Compressive Strength (CCS) (Average Actual Data is 35.818)
3	286.5	18	56.2506
4	244.2	11	56.9138
5	219.1	18	56.448
6	205.8	10	56.8346

No. of Clusters	Sum Of Squared Errors (SSE)	Number Of Iterations	Concrete Compressive Strength (CCS) (Average Actual Data is 35.818)
7	182.6	30	57.042
8	176.1	12	57.2971
9	159.198	17	56.9463
12	138.4	22	54.764
15	122.486	26	53.4718
20	104.0	24	55.7447
25	94.18	16	56.8314
30	83.77	17	63.3709
50	62.3	16	67.23

Table 8 and figure 5 show the prediction of the Concrete Compressive Strength (CCS) by applying both K-Means and KSOM using WEKA. We find the actual average of Concrete Compressive Strength (CCS) is equal to 35.818. By comparing the results of the Concrete Compressive Strength CCS of both algorithms, we find a slight intersection or similarity between K-Means and KSOM algorithm.

Table 8.

Concrete Compressive Strength (CCS) Prediction K-Means vs. KSOM

No. of Clusters	Concrete Compressive Strength (CCS) Prediction (Average Actual Data is 35.818)	
	K-Means	KSOM
2	36.9804	34.8796
3	56.2506	55.2417
4	56.9138	56.9722
5	56.448	56.179
6	56.8346	56.88
8	57.2971	58.616
10	58.7342	58.9955
CCS Prediction Average	54.2084	53.9663

The values obtained using K-Means and KSOM in WEKA, indicate that the estimation results of CCS predication for both algorithms are very close. The results show that the K-Means can be successfully used to give a more accurate prediction for increasing the Concrete Compressive Strength (CCS) (54.2084) than the average actual data (35.818) and KSOM.

This study applied three algorithms and compared their results to find the main components that affect the Concrete Compressive Strength (CCS) using the WEKA tool. It was noted that the results of the EM algorithm is one of the most accurate and effective tools for finding the factors affecting the Concrete Compressive Strength. On the other hand, K-Means and KSOM algorithms are the most adequate algorithms for improving Concrete Compressive Strength mix.

Results of this study can be used to predict the main factors that affect the compressive strength of concrete and the mixtures of concrete.

Table 6 shows the main predicted components that affect the concrete compressive strength. These components are Blast Furnace Slag, Fly Ash, Superplasticizer, Coarse Aggregate and Fine

Aggregate. The analysis of the data in Table 8 and Table 9 show a significant correlation between the prediction of improving the CCS and the main factors that affect the CCS. The values for these parameters are similar among the three Data Mining algorithms. These results are very important because they provide us with the threshold values that improve the CCS. These parameters increased the performance of CSS from 35.818 to 58.9955. They were also able to increase the performance model from 36% to 59% of CCS.

Table 9.

Summary of the main components that improve the performance of concrete compressive strength.

Predictive parameters	K-Means	EM	KSOM	Average Value (kg/m3 mixture)	Mean
Blast Furnace Salg	-	0.4714		179.7	73.896
Fly Ash	0.0	0.0	0.0	100.05	54.188
Superplasticizer	0.0	0.0253	0.0355	16.1	6.205
Coarse Aggregate	867.525			973	972.91
Fine Aggregate	727.4851			793.3	773.58

Furthermore, these results reinforce the predication model through improving the CCS and reducing the cost of the concrete mixtures. For example, the cost of fly ash is varying and expressive. In our model, it is important to note that the cost of fly ash is beyond concrete mixture because the three Data Mining algorithms suggest a threshold value of zero for fly ash.

Overall, applying the different algorithms of Data Mining to our datasets proved to be very effective in predicting and improving the concrete compressive strength.

While all input parameters are very important and effective in predicting concrete compressive strength based on the laboratory test, our analysis shows that there are more effective parameters in our input that improve the performance of concrete compressive strength.

Our analysis shows that the performance of each Data Mining algorithm is similar yet with a small difference between them. Moreover, each one of them is appropriate for the prediction for improving CCS.

CONCLUSION

The main aim of this present study is to find the key components that affect Concrete Compressive Strength (CCS). To accomplish this research, the datasets were selected, then three data mining algorithms (EM, KSOM and K-Means) were applied. The actual input parameters consists of eight parameters and one output CCS. The input parameters were examined against CCS using the three data mining algorithms. The results were analyzed and discussed. The study used WEKA as a tool for data mining techniques.

This study focuses on including all the different components of the concrete in our prediction model and in finding the main factors that influence the high performance of concrete to increase the Concrete Compressive Strength (CCS) mix, using three different algorithms.

Results showed that using data mining techniques is highly effective in predicting the main factors that affect CCS. The analysis shows that K-Means and KSOM algorithms are the most accurate algorithm to predict the CCS. At the same time, EM is useful for predicting the main factors that affect the CCS.

In general, data mining techniques are very effective tools in predicting concrete compressive strength as well as the main factors that affect and improve the performance of concrete compressive strength. Our study can be expanded to include additional parameters, such as humidity, moisture, temperature, and methods of mixing etc. These parameters might be able to improve the prediction of CCS.

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